

PCT

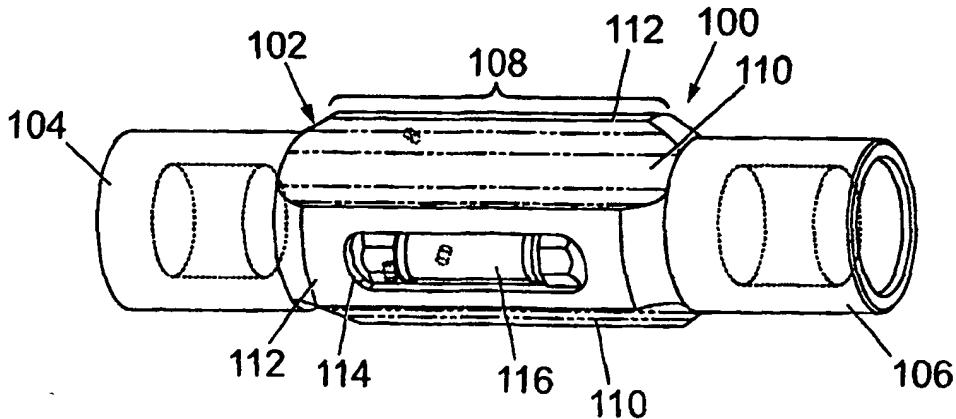
WORLD INTELLECTUAL PROPERTY ORGANIZATION  
International Bureau



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 : <b>E21B 29/00, 29/10, B21D 17/04, 39/04, 39/10</b>	A2	(11) International Publication Number: <b>WO 00/37766</b> (43) International Publication Date: <b>29 June 2000 (29.06.00)</b>
(21) International Application Number: <b>PCT/GB99/04225</b>		(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).
(22) International Filing Date: <b>21 December 1999 (21.12.99)</b>		
(30) Priority Data:		
9828234.6 22 December 1998 (22.12.98) GB 9900835.1 15 January 1999 (15.01.99) GB 9923783.6 8 October 1999 (08.10.99) GB 9924189.5 13 October 1999 (13.10.99) GB		
(71) Applicant ( <i>for all designated States except US</i> ): ASTEC DEVELOPMENTS LIMITED [GB/GB]; Burn of Daff Farm, Downies, Portlethen, Aberdeen AB1 4QX (GB).		
(72) Inventor; and		
(75) Inventor/Applicant ( <i>for US only</i> ): SIMPSON, Neil, Andrew, Abercrombie [GB/GB]; Burn of Daff Farm, Downies, Portlethen, Aberdeen AB1 4QX (GB).		
(74) Agent: PACITTI, Paolo; Murgitroyd & Company, 373 Scotland Street, Glasgow G5 8QA (GB).		

(54) Title: PROCEDURES AND EQUIPMENT FOR PROFILING AND JOINTING OF PIPES



(57) Abstract

Methods and apparatus for shaping pipes, tubes, liners, or casing at downhole locations in wells. Use is made of rollers bearing radially outwards against the inside wall of the pipe (etc.), the rollers being rolled around the pipe to cause outward plastic deformation which expands and shapes the pipe to a desired profile. Where one pipe is inside another, the two pipes can be joined without separate components (except optional seals). Landing nipples and liner hangers can be formed in situ. Valves can be deployed to a selected downhole location and there sealed to the casing or liner without separate packers. Casing can be deployed downhole in reduced-diameter lengths and then expanded to case a well without requiring larger diameter bores and casing further uphole. The invention enables simplified downhole working, and enables a well to be drilled and produced with the minimum downhole bore throughout its depth, obviating the need for large bores. When expanding lengths of casing, the casing does not need to be anchored or made pressure-tight. The profiling/expansion tools of the invention can be deployed downhole on coiled tubing, and operated without high tensile loads on the coiled tubing.

**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece			TR	Turkey
BG	Bulgaria	HU	Hungary	ML	Mali	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MN	Mongolia	UA	Ukraine
BR	Brazil	IL	Israel	MR	Mauritania	UG	Uganda
BY	Belarus	IS	Iceland	MW	Malawi	US	United States of America
CA	Canada	IT	Italy	MX	Mexico	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NE	Niger	VN	Viet Nam
CG	Congo	KE	Kenya	NL	Netherlands	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NO	Norway	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	NZ	New Zealand		
CM	Cameroon			PL	Poland		
CN	China	KR	Republic of Korea	PT	Portugal		
CU	Cuba	KZ	Kazakhstan	RO	Romania		
CZ	Czech Republic	LC	Saint Lucia	RU	Russian Federation		
DE	Germany	LI	Liechtenstein	SD	Sudan		
DK	Denmark	LK	Sri Lanka	SE	Sweden		
EE	Estonia	LR	Liberia	SG	Singapore		

1       **PROCEDURES AND EQUIPMENT FOR**  
2       **PROFILING AND JOINTING OF PIPES.**

3       This invention relates to procedures and equipment for  
4       profiling and jointing of pipes, and relates more  
5       particularly but not exclusively to methods and  
6       apparatus for the shaping and/or expansion and/or  
7       conjoining of tubular casings in wells.

8       In the hydrocarbon exploration and production industry  
9       there is a requirement to deploy tubular casings in  
10      relatively narrow-bore wells, and to expand the  
11      deployed casing *in situ*. The casing may require to be  
12      expanded throughout its length in order to line a bore  
13      drilled through geological material; the casing may  
14      additionally or alternatively require to be expanded at  
15      one end where it overlaps and lies concentrically  
16      within another length of previously deployed casing in  
17      order to form a swaged joint between the two lengths of  
18      casing. Proposals have been made that a slotted metal  
19      tube be expanded by mechanically pulling a mandrel  
20      through the tube, and that a solid-walled steel tube be  
21      expanded by hydraulically pushing a part-conical  
22      ceramic plunger through the tube. In both of these  
23      proposals, very high longitudinal forces would be  
24      exerted throughout the length of the tubing, which  
25      accordingly would require to be anchored at one end.

1 Where mechanical pulling is to be employed, the pulling  
2 force would require to be exerted through a drillstring  
3 (in relatively large diameter wells) or through coiled  
4 tubing (in relatively small diameter wells). The  
5 necessary force would become harder to apply as the  
6 well became more deviated (i.e. more non-vertical), and  
7 in any event, coiled tubing may not tolerate high  
8 longitudinal forces. Where hydraulic pushing is to be  
9 employed, the required pressure may be hazardously  
10 high, and in any event the downhole system would  
11 require to be pressure-tight and substantially leak-  
12 free. (This would preclude the use of a hydraulically  
13 pushed mandrel for the expansion of slotted tubes).  
14 The use of a fixed-diameter mandrel or plug would make  
15 it impracticable or impossible to control or to vary  
16 post-deformation diameter after the start of the  
17 expansion procedure.

18 It is therefore an object of the invention to provide  
19 new and improved procedures and equipment for the  
20 profiling or jointing of pipes or other hollow tubular  
21 articles, which obviate or mitigate at least some of  
22 the disadvantages of the prior art.

23 In the following specification and claims, references  
24 to a "pipe" are to be taken as references to a hollow  
25 tubular pipe and to other forms of hollow tubular  
26 article, and references to "profiling" are to be taken  
27 as comprising alteration of shape and/or dimension(s)  
28 which alteration preferably takes place substantially  
29 without removal of material.

30

31 According to a first aspect of the present invention  
32 there is provided a profiling method for profiling a  
33 pipe or other hollow tubular article, the profiling

1 method comprising the steps of applying a roller means  
2 to a part of the pipe bore selected to be profiled,  
3 translating the roller means across the bore in a  
4 direction including a circumferential component while  
5 applying a force to the roller means in a radially  
6 outwards direction with respect to the longitudinal  
7 axis of the pipe, and continuing such translation and  
8 force application until the pipe is plastically  
9 deformed substantially into the intended profile.

10 The deformation of the pipe may be accomplished by  
11 radial compression of the pipe wall or by  
12 circumferential stretching of the pipe wall, or by a  
13 combination of such radial compression and  
14 circumferential stretching.

15 Said direction may be purely circumferential, or said  
16 direction may partly circumferential and partly  
17 longitudinal.

18 Said roller means is preferably peripherally profiled  
19 to be complementary to the profile into which the  
20 selected part of the pipe bore is intended to be  
21 formed.

22 The selected part of the pipe bore may be remote from  
23 an open end of the pipe, and the profiling method then  
24 comprises the further steps of inserting the roller  
25 means into the open end of the pipe (if the roller  
26 means is not already in the pipe), and transferring the  
27 roller means along the pipe to the selected location.  
28 Transfer of the roller means is preferably accomplished  
29 by the step of actuating traction means coupled to or  
30 forming part of the roller means and effective to apply  
31 along-pipe traction forces to the roller means by

1 reaction against parts of the pipe bore adjacent the  
2 roller means.

3 The profiling method according to the first aspect of  
4 the present invention can be applied to the profiling  
5 of casings and liners deployed in a well (e.g. a  
6 hydrocarbon exploration or production well), and the  
7 profile created by use of the method may be a liner  
8 hanger, or a landing nipple, or another such downhole  
9 profile of the type which previously had to be provided  
10 by inserting an annular article or mechanism into the  
11 well, lowering it the required depth, and there  
12 anchoring it (which required either a larger diameter  
13 of well for a given through diameter, or a restricted  
14 through diameter for a given well diameter, together  
15 with the costs and inconvenience of manufacturing and  
16 installing the article or mechanism). Additionally or  
17 alternatively, the profiling method according to the  
18 first aspect of the present invention can be applied to  
19 increasing the diameter of a complete length of pipe;  
20 for example, where a well has been cased to a certain  
21 depth (the casing having a substantially constant  
22 diameter), the casing can be extended downwardly by  
23 lowering a further length of pipe (of lesser diameter  
24 such that it freely passes down the previously  
25 installed casing) to a depth where the top of the  
26 further length lies a short way into the lower end of  
27 the previously installed casing and there expanding the  
28 upper end of the further length to form a joint with  
29 the lower end of the previously installed casing (e.g.  
30 by using the method according to the second aspect of  
31 the present invention), followed by circumferential  
32 expansion of the remainder of the further length to  
33 match the bore of the previously installed casing.

1 According to a second aspect of the present invention  
2 there is provided a conjoining method for conjoining  
3 two pipes or other hollow tubular articles, said  
4 conjoining method comprising the steps of locating one  
5 of the two pipes within and longitudinally overlapping  
6 one of the other of the two pipes, applying roller  
7 means to a part of the bore of the inner of the two  
8 pipes at a location where it is intended that the two  
9 pipes be conjoined, translating the roller means across  
10 the bore in a direction including a circumferential  
11 component while applying a radially outwardly directed  
12 force to the roller means, and continuing such  
13 translation and force application until the inner pipe  
14 is plastically deformed into permanent contact with the  
15 outer pipe and is thereby conjoined thereto.

16 Said deformation may be accomplished by radial  
17 compression of the pipe wall or by circumferential  
18 stretching of the pipe wall, or by a combination of  
19 such radial compression and circumferential stretching.

20 Said direction may be purely circumferential, or said  
21 direction may be partly circumferential and partly  
22 longitudinal.

23 The location where the pipes are intended to be  
24 conjoined may be remote from an accessible end of the  
25 bore, and the conjoining method then comprises the  
26 further steps of inserting the roller means into the  
27 accessible end of the bore (if the roller means is not  
28 already in the bore), and transferring the roller means  
29 to the intended location. Transfer of the roller means  
30 is preferably accomplished by the step of actuating  
31 traction means coupled to or forming part of the roller  
32 means and effective to apply along-bore traction forces

1 to the roller means by reaction against parts of the  
2 pipe bore adjacent the roller means.

3 The conjoining method according to the second aspect of  
4 the present invention can be applied to the mutual  
5 joining of successive lengths of casing or liner  
6 deployed in a well (e.g. a hydrocarbon exploration or  
7 production well), such that conventional screw-threaded  
8 connectors are not required.

9 According to third aspect of the present invention,  
10 there is provided expansion apparatus for expanding a  
11 pipe or other hollow tubular article, said expansion  
12 apparatus comprising roller means constructed or  
13 adapted for rolling deployment against the bore of the  
14 pipe, said roller means comprising at least one set of  
15 individual rollers each mounted for rotation about a  
16 respective rotation axis which is generally parallel to  
17 the longitudinal axis of the apparatus, the rotation  
18 axes of said at least one set of rollers being  
19 circumferentially distributed around the expansion  
20 apparatus and each being radially offset from the  
21 longitudinal axis of the expansion apparatus, the  
22 expansion apparatus being selectively rotatable around  
23 its longitudinal axis.

24 The rotation axes of said at least one set of rollers  
25 may conform to a first regime in which each said  
26 rotation axis is substantially parallel to the  
27 longitudinal axis of the expansion apparatus in a  
28 generally cylindrical configuration, or the rotation  
29 axes of said at least one set of rollers may conform to  
30 a second regime in which each said rotation axis lies  
31 substantially in a respective radial plane including  
32 the longitudinal axis of the expansion apparatus and

1       the rotation axes each converge substantially towards a  
2       common point substantially on the longitudinal axis of  
3       the expansion apparatus in a generally conical  
4       configuration, or the rotation axes of said at least  
5       one set of rollers may conform to third regime in which  
6       each said rotation axis is similarly skewed with  
7       respect to the longitudinal axis of the expansion  
8       apparatus in a generally helical configuration which  
9       may be non-convergent (cylindrical) or convergent  
10      (conical). Rollers in said first regime are  
11      particularly suited to profiling and finish expansion  
12      of pipes and other hollow tubular articles, rollers in  
13      said second regime are particularly suited to  
14      commencing expansion in, and to flaring of pipes, and  
15      other hollow tubular articles, while rollers in said  
16      third regime are suited to providing longitudinal  
17      traction in addition to such functions of the first or  
18      second regimes as are provided by other facets of the  
19      roller axes besides skew. The expansion apparatus may  
20      have only a single such set of rollers, or the  
21      expansion apparatus may have a plurality of such sets  
22      of rollers which may conform to two or more of the  
23      aforesaid regimes of roller axis alignments; in a  
24      particular example where the expansion apparatus has a  
25      set of rollers conforming to the second regime located  
26      at leading end of the exemplary expansion apparatus and  
27      another set of rollers conforming to the first regime  
28      located elsewhere on the exemplary expansion apparatus,  
29      this exemplary expansion apparatus is particularly  
30      suited to expanding complete lengths of hollow tubular  
31      casing by reason of the conically disposed leading set  
32      of rollers opening up previously unexpanded casing and  
33      the following set of cylindrically disposed rollers  
34      finish-expanding the casing to its intended final  
35      diameter; if this exemplary expansion apparatus were

1 modified by the addition of a further set of rollers  
2 conforming to third regime with non-convergent axes,  
3 this further set of rollers could be utilised for the  
4 purpose of applying traction forces to the apparatus by  
5 means of the principles described in the present  
6 inventor's previously published PCT patent application  
7 WO93/24728-A1, the contents of which are incorporated  
8 herein by reference.

9 The rollers of said expansion apparatus may each be  
10 mounted for rotation about its respective rotation axis  
11 substantially without freedom of movement along its  
12 respective rotation axis, or the rollers may each be  
13 mounted for rotation about its respective rotation axis  
14 with freedom of movement along its respective rotation  
15 axis, preferably within predetermined limits of  
16 movement. In the latter case (freedom of along-axis  
17 movement within predetermined limits), this is  
18 advantageous in the particular case of rollers  
19 conforming to the afore-mentioned second regime (i.e. a  
20 conical array of rollers) in that the effective maximum  
21 outside diameter of the rollers depends on the position  
22 of the rollers along the axis of the expansion  
23 apparatus and this diameter is thereby effectively  
24 variable; this allows relief of radially outwardly  
25 directed forces by longitudinally retracting the  
26 expansion apparatus to allow the rollers collectively  
27 to move longitudinally in the convergent direction and  
28 hence collectively to retract radially inwards away  
29 from the bore against which they were immediately  
30 previously pressing.

31 According to a fourth aspect of the present invention,  
32 there is provided profiling/conjoining apparatus for  
33 profiling or conjoining pipes or other hollow tubular

1 articles, said profiling/conjoining apparatus  
2 comprising roller means and radial urging means  
3 selectively operable to urge the roller means radially  
4 outwards of a longitudinal axis of the  
5 profiling/conjoining apparatus, the radial urging means  
6 causing or allowing the roller means to move radially  
7 inwards towards the longitudinal axis of the  
8 profiling/conjoining apparatus when the radial urging  
9 means is not operated, the roller means comprising a  
10 plurality of individual rollers each mounted for  
11 rotation about a respective rotation axis which is  
12 substantially parallel to the longitudinal axis of the  
13 profiling/conjoining apparatus, the rotation axes of  
14 the individual rollers being circumferentially  
15 distributed around the apparatus and each said rotation  
16 axis being radially offset from the longitudinal axis  
17 of the profiling/conjoining apparatus, the  
18 profiling/conjoining apparatus being selectively  
19 rotatable around its longitudinal axis to translate the  
20 roller means across the bore of a pipe against which  
21 the roller means is being radially urged.

22

23 The radial urging means may comprise a respective  
24 piston on which each said roller is individually  
25 rotatably mounted, each said piston being slidably  
26 sealed in a respective radially extending bore formed  
27 in a body of the profiling/conjoining apparatus, a  
28 radially inner end of each said bore being in fluid  
29 communication with fluid pressure supply means  
30 selectively pressurisable to operate said radial urging  
31 means.

32 Alternatively, the radial urging means may comprise bi-  
33 conical race means upon which each said individual  
34 roller rolls in use of the profiling/conjoining

1       apparatus, and separation variation means selectively  
2       operable controllably to vary the longitudinal  
3       separation of the two conical races of the bi-conical  
4       race means whereby correspondingly to vary the radial  
5       displacement of each said roller rotation axis from the  
6       longitudinal axis of the profiling/conjoining  
7       apparatus. The separation variation means may comprise  
8       hydraulic linear motor means selectively pressurisable  
9       to drive one of said two cones longitudinally towards  
10      and/or away from the other said cone.

11      Embodiments of the invention will now be described by  
12      way of example, with reference to the accompanying  
13      drawings wherein :

14           Fig. 1 is a plan view of a first embodiment  
15          of profiling tool;

16           Fig. 2 is an elevation of the profiling tool  
17          of Fig. 1;

18           Fig. 3 is a sectional perspective view of the  
19          profiling tool of Figs. 1 & 2, the section  
20          being taken on the line III-III in Fig. 2;  
21           Fig. 4 is an exploded perspective view of the  
22          profiling tool of Figs. 1-4;

23           Figs. 5A, 5B, & 5C are simplified sectional  
24          views of three successive stages of operation  
25          of the profiling tool of Figs. 1-4;

26           Fig. 6 is a schematic diagram illustrating  
27          the metallurgical principle underlying the  
28          operational stage depicted in Fig. 5C;

1       Figs. 7A & 7B are illustrations corresponding  
2       to Figs. 5A & 5B but in respect of a variant  
3       of the Figs. 1-4 profiling tool having two  
4       rollers instead of three;

5       Figs. 8A & 8B are illustrations corresponding  
6       to Figs. 5A & 5B but in respect of a variant  
7       of the Figs. 1-4 profiling tool having five  
8       rollers instead of three;

9       Figs. 9A & 9B respectively illustrate  
10      starting and finishing stages of a first  
11      practical application of the profiling tool  
12      of Figs. 1-4;

13      Figs. 10A & 10B respectively illustrate  
14      starting and finishing stages of a second  
15      practical application of the profiling tool  
16      of Figs. 1-4;

17      Figs. 11A & 11B respectively illustrate  
18      starting and finishing stages of a third  
19      practical application of the profiling tool  
20      of Figs. 1-4;

21      Figs. 12A & 12B respectively illustrate  
22      starting and finishing stages of a fourth  
23      practical application of the profiling tool  
24      of Figs. 1-4;

25      Figs. 13A & 13B respectively illustrate  
26      starting and finishing stages of a fifth  
27      practical application of the profiling tool  
28      of Figs. 1-4;

1 Figs. 14A & 14B respectively illustrate  
2 starting and finishing stages of a sixth  
3 practical application of the profiling tool  
4 of Figs. 1-4;

5 Figs. 15A & 15B respectively illustrate  
6 starting and finishing stages of a seventh  
7 practical application of the profiling tool  
8 of Figs. 1-4;

9 Figs. 16A & 16B respectively depict starting  
10 and finishing stages of an eighth practical  
11 application of the profiling tool of Figs. 1-  
12 4;

13 Figs. 17A & 17B respectively depict starting  
14 and finishing stages of a ninth practical  
15 application of the profiling tool of Figs. 1-  
16 4;

17 Fig. 18 schematically depicts a tenth  
18 practical application of the profiling tool  
19 of Figs. 1-4;

20 Fig. 19 schematically depicts an eleventh  
21 practical application of the profiling tool  
22 of Figs. 1-4;

23 Fig. 20 is a longitudinal elevation of a  
24 first embodiment of expansion tool in  
25 accordance with the present invention;

26

27 Fig. 21 is a longitudinal elevation, to an  
28 enlarged scale, of part of the expansion tool  
29 of Fig. 20;

1       Fig. 21A is an exploded view of the tool part  
2       illustrated in Fig. 20;

3       Fig. 22 is a longitudinal section of the tool  
4       part illustrated in Fig. 20;

5       Fig. 23 is a longitudinal section of the  
6       expansion tool illustrated in Fig. 21;

7       Fig. 24 is an exploded view of part of the  
8       expansion tool illustrated in Fig. 20;

9       Fig. 25 is a longitudinal section of an  
10      alternative form of the tool part illustrated  
11      in Fig. 21;

12      Fig. 26 is a longitudinal section of a  
13      technical variant of the tool part  
14      illustrated in Fig. 21;

15      Fig. 27 is a longitudinal elevation of a  
16      second embodiment of expansion tool in  
17      accordance with the present invention;

18      Figs. 28A, 28B, & 28C are respectively a  
19      longitudinal section, a longitudinal  
20      elevation, and a simplified end view of a  
21      third embodiment of expansion tool in  
22      accordance with the present invention;

23      Figs. 29A & 29B are longitudinal sections of  
24      a fourth embodiment of expansion tool in  
25      accordance with the present invention,  
26      respectively in expanded and contracted  
27      configurations; and

1       Fig. 30 is a longitudinal section of a fifth  
2       embodiment of expansion tool in accordance  
3       with the present invention.

4       Referring first to Figs. 1 & 2, these depict a three-  
5       roller profiling tool 100 in accordance with the  
6       present invention. The tool 100 has a body 102 which  
7       is hollow and generally tubular, with conventional  
8       screw-threaded end connectors 104 & 106 for connection  
9       to other components (not shown) of a downhole assembly.  
10      The end connectors 104 & 106 are of reduced diameter  
11      (compared to the outside diameter of the longitudinally  
12      central body part 108 of the tool 100), and together  
13      with three longitudinal flutes 110 on the central body  
14      part 108, allow the passage of fluids along the outside  
15      of the tool 100. The central body part 108 has three  
16      lands 112 defined between the three flutes 110, each  
17      land 112 being formed with a respective recess 114 to  
18      hold a respective roller 116 (see also Figs. 3 & 4).  
19      Each of the recesses 114 has parallel sides and extends  
20      radially from the radially perforated tubular core 115  
21      of the tool 100 to the exterior of the respective land  
22      112. Each of the mutually identical rollers 116 is  
23      near-cylindrical and slightly barrelled (i.e. of slight-  
24      ly greater diameter in its longitudinally central  
25      region than at either longitudinal end, with a  
26      generally convex profile having a discontinuity-free  
27      transition between greatest and least diameters). Each  
28      of the rollers 116 is mounted by means of a bearing 118  
29      at each end of the respective roller for rotation about  
30      a respective rotation axis which is parallel to the  
31      longitudinal axis of the tool 100 and radially offset  
32      therefrom at 120-degree mutual circumferential  
33      separations around the central part 108. The bearings  
34      118 are formed as integral end members of radially

1       slidable pistons 120, one piston 120 being slidably  
2       sealed within each radially extending recess 114. The  
3       inner end of each piston 120 is exposed to the pressure  
4       of fluid within the hollow core of the tool 100 by way  
5       of the radial perforations in the tubular core 115; in  
6       use of the tool 100, this fluid pressure will be the  
7       downhole pressure of mud or other liquid within a  
8       drillstring or coiled tubing at or near the lower end  
9       of which the toll 100 will be mounted. Thus by  
10      suitably pressurising the core 115 of the tool 100, the  
11      pistons 120 can be driven radially outwards with a  
12      controllable force which is proportional to the  
13      pressurisation, and thereby the piston-mounted rollers  
14      116 can be forced against a pipe bore in a manner to be  
15      detailed below. Conversely, when the pressurisation of  
16      the core 115 of the tool 100 is reduced to below  
17      whatever is the ambient pressure immediately outside  
18      the tool 100, the pistons 120 (together with the  
19      piston-mounted rollers 116) are allowed to retract  
20      radially back into their respective recesses 114.  
21      (Such retraction can optionally be encouraged by  
22      suitably disposed springs (not shown)).

23     The principles by which the profiling tool 100  
24     functions will now be detailed with reference to Figs.  
25     5 and 6.

26     Fig. 5A is a schematic end view of the three rollers  
27     116 within the bore of an inner pipe 180, the remainder  
28     of the tool 100 being omitted for the sake of clarity.  
29     The pipe 180 is nested within an outer pipe 190 whose  
30     internal diameter is somewhat greater than the outside  
31     diameter of the inner pipe 180. As depicted in Fig.  
32     5A, the core of the tool 100 has been pressurised just  
33     sufficiently to push the pistons 120 radially outwards

1 and thereby to bring the piston-mounted rollers 116  
2 into contact with the bore of the inner pipe 180, but  
3 without at first exerting any significant forces on the  
4 pipe 180.

5 Fig. 5B depicts the next stage of operation of the  
6 profiling tool 100, in which the internal  
7 pressurisation of the tool 100 is increased  
8 sufficiently above its external pressure (i.e. the  
9 pressure in the region between the exterior of the tool  
10 100 and the bore of the pipe 180) such that the rollers  
11 116 each exert a substantial outward force, as denoted  
12 by the arrow-headed vectors superimposed on each roller  
13 116 in Fig. 5B. The effect of such outward forces on  
14 the rollers 116 is circumferentially to deform the wall  
15 of the inner pipe 180 (with concomitant distortion of  
16 the pipe 180 which is shown in Fig. 5B for the sake of  
17 clarity). When the roller-extended lobes touch the  
18 bore of the outer pipe 190, the inner pipe 180 is  
19 thereby anchored against rotation with respect to the  
20 outer pipe 190, or at least constrained against free  
21 relative rotation. By simultaneously rotating the  
22 tool 100 around its longitudinal axis (which will  
23 normally be substantially coincident with the  
24 longitudinal axis of the pipe 180), the circumferential  
25 deformation of the wall of the pipe 180 tends to become  
26 uniform around the pipe 180, and the pipe 180  
27 circumferentially extends into substantially uniform  
28 contact with the bore of the outer pipe 190, as  
29 depicted in Fig. 5C. This occurs due to the rollers  
30 causing rolling compressive yield of the inner pipe  
31 wall to cause reduction in wall thickness, increase in  
32 circumference and consequent increase in diameter.  
33 (Rotation of the tool 100 can be undertaken by any  
34 suitable procedure, several of which will subsequently

1       be described). Circumferential deformation of the pipe  
2       180 is initially elastic and may subsequently be  
3       plastic. A secondary effect of the process is to  
4       generate compressive hoop stress in the internal  
5       portion of the inner tube and an interference fit  
6       between the inner tube and the outer tube.

7       From the stage depicted in Fig. 5C wherein the inner  
8       pipe 180 has initially been circumferentially deformed  
9       just into full contact with the bore of the outer pipe  
10      190 (thus removing the previous clearance between the  
11      pipes 180 and 190) but without stretching or distortion  
12      of the outer pipe 190, continued (and possibly  
13      increased) internal pressurisation of the tool 100 in  
14      conjunction with continued rotation of the tool 100 (at  
15      the same rotational speed or at a suitably different  
16      rotational speed) forces the inner pipe 180 outwards  
17      against the resistance to deformation of the outer pipe  
18      190. Since the inner pipe 180 is now backed by the  
19      outer pipe 190 with respect to the radially outward  
20      forces being applied by the rollers 116 such that the  
21      wall of the inner pipe 180 is now pinched between the  
22      rollers 116 and the outer pipe 190, the mechanism of  
23      deformation of the pipe 180 changes to compressive  
24      extension by rolling (i.e. the same thinning/extension  
25      principle as prevails in conventional steel rolling  
26      mills, as schematically depicted in Fig. 6 wherein the  
27      circular rolling of Figs. 5A-5C has been opened out and  
28      developed into an equivalent straight-line rolling  
29      procedure to enhance the analogy with steel rolling  
30      mills).

31      When operation of the tool 100 is terminated and the  
32      rollers 116 are caused or allowed to retract radially  
33      into the body of the tool 100 thereby to relieve the

1       pipes 180 of all contact with the rollers 116, the  
2       induced compressive hoop stress created in the wall of  
3       the inner pipe 180 due to the rolling process causes  
4       the inner pipe 180 to remain in contact with the inner  
5       wall of the outer pipe 190 with very high contact  
6       stresses at their interface.

7       Figs. 7A & 7B correspond to Figs. 5A & 5B, and  
8       schematically depict the equivalent stages of operation  
9       of a two-roller profiling tool (not otherwise shown per  
10      se) in order to illustrate the effects of using a  
11      profiling tool having fewer than the three rollers of  
12      the profiling tool 100 detailed above.

13      Figs. 8A & 8B also correspond to Figs. 5A & 5B, and  
14      schematically depict the equivalent stages of operation  
15      of a five-roller profiling tool (not otherwise shown  
16      per se) in order to illustrate the effects of using a  
17      profiling tool having more than the three rollers of  
18      the profiling tool 100 detailed above.

19      It should be noted that though the very high contact  
20      stresses existing at the interface of the inner pipe  
21      180 and outer pipe 190 may cause the outer pipe 190 to  
22      expand elastically or plastically, it is not a  
23      requirement of this process that the outer pipe 190 is  
24      capable of any expansion whatsoever. The process would  
25      still result in the high contact stresses between the  
26      inner pipe 180 and the outer pipe 190 even if the outer  
27      pipe 190 was incapable of expansion, eg by being thick  
28      walled, by being encased in cement, or being tightly  
29      embedded in a rock formation.

30      Various practical applications of profiling tools in  
31      accordance with the invention will now be described

1       with reference to Figs. 9 - 19. The profiling tool  
2       used in these practical applications may be the  
3       profiling tool 100 detailed above, or some variant of  
4       such a profiling tool which differs in one or more  
5       details without departing from the scope of the  
6       invention.

7       Fig. 9A schematically depicts the upper end of a first  
8       pipe or casing 200 concentrically nested within the  
9       lower end of a second pipe or casing 202 whose bore  
10      (internal diameter) is marginally greater than the  
11      outside diameter of the first pipe or casing 200. A  
12      profiling tool (not shown) is located within the upper  
13      end of the first pipe or casing 200 where it is  
14      overlapped by the second pipe or casing 202. The  
15      rollers of the profiling tool are then radially  
16      extended into contact with the bore of the inner pipe  
17      or casing 200 by means of internal pressurisation of  
18      the profiling tool (or by any other suitable means  
19      which may alternatively be utilised for forcing the  
20      rollers radially outwards of the profiling tool). The  
21      outward forces exerted by the rollers on the bore of  
22      the first pipe or casing 200 are schematically depicted  
23      by the force-vector-depicting arrows 204.

24     From the starting situation depicted in Fig. 9A,  
25     combined with suitable rotation of the profiling tool  
26     about its longitudinal axis (which is substantially  
27     coincident with the longitudinal axis of the first pipe  
28     or casing 200), the finish situation schematically  
29     depicted in Fig. 9B is arrived at, namely the upper end  
30     of the inner pipe or casing 200 is profiled by  
31     permanent plastic expansion into conjunction with the  
32     lower end of the second pipe or casing 202. Thereby  
33     the two pipes or casings are permanently conjoined

1 without the use of any form of separate connector and  
2 without the use of conventional joining techniques such  
3 as welding.

4 Figs. 10A & 10B correspond to Figs. 9A & 9B  
5 respectively, and schematically illustrate an optional  
6 modification of the profiling/conjoining technique  
7 described with respect to Figs. 9A & 9B. The  
8 modification consists of applying an adherent coating  
9 206 of hard particulate material to the exterior of the  
10 upper end of the first (inner) pipe or casing 200 prior  
11 to its location within the lower end of the second  
12 (outer) pipe or casing 202. The hard particulate  
13 material may consist of carbide granules, e.g. tungsten  
14 carbide granules such as are commonly used to coat  
15 downhole reamers. In the application depicted in Figs.  
16 10A & 10B, the hard particulate material is selected  
17 for its crush resistance rather than for its abrasive  
18 qualities, and in particular the material is selected  
19 for its ability to interpenetrate the meeting surfaces  
20 of two sheets of steel which are pressed together with  
21 the hard particulate material sandwiched between the  
22 steel components. Such sandwiching is schematically  
23 depicted in Fig. 10B. Tests have shown a surprising  
24 increase in resistance to separation forces of pipes or  
25 other articles conjoined by a profiling tool in  
26 accordance with the invention to withstand, where a  
27 coating of hard particulate material was first  
28 interposed between the parts being conjoined. It is  
29 preferred that of the whole area to be coated, only a  
30 minority of the area is actually covered with the  
31 particulate material, e.g. 10% of the area. (It is  
32 believed that a higher covering factor actually reduces  
33 the interpenetration effect and hence diminishes the  
34 benefits below the optimum level).

1 Referring now to Figs. 11A & 11B, these schematically  
2 depict an optional modification of the Fig. 9  
3 conjoining procedure to achieve improved sealing  
4 between the two conjoined pipes or casings. As  
5 depicted in Fig. 11A, the modification comprises  
6 initially fitting the exterior of the first (inner)  
7 pipe or casing 200 with a circumferentially extending  
8 and part-recessed ductile metal ring 208, which may  
9 (for example) be formed of a suitable copper alloy or a  
10 suitable tin/lead alloy. The modification also  
11 comprises initially fitting the exterior of the first  
12 (inner) pipe or casing 200 with a circumferentially  
13 extending and fully recessed elastomeric ring 210. As  
14 depicted in Fig. 11B, the rings 208 and 210 become  
15 crushed between the two pipes or casings 200 & 202  
16 after these have been conjoined by the profiling tool,  
17 and thereby a mutual sealing is achieved which may be  
18 expected to be superior to the basic Fig. 9 arrangement  
19 in otherwise equal circumstances. In suitable  
20 situations, one or other of the sealing rings 208 and  
21 210 may be omitted or multiplied to achieve a necessary  
22 or desirable level of sealing (e.g. as in Fig. 12).

23 Referring now to Figs. 12A & 12B, these schematically  
24 depict an arrangement in which the lower end of the  
25 second (outer) casing 202 is pre-formed to have a  
26 reduced diameter so as to function as a casing hanger.  
27 The upper end of the first (inner) casing 200 is  
28 correspondingly pre-formed to have an increased  
29 diameter which is complementary to the reduced diameter  
30 of the casing hanger formed at the lower end of the  
31 outer casing 202, as depicted in Fig. 12A. Optionally,  
32 the upper end of the first (inner) casing 200 may be  
33 provided with an external seal in the form of an  
34 elastomeric ring 212 flush-mounted in a circumferential

1 groove formed in the outer surface of the first casing  
2 200. The arrangement of Fig. 12A differs from the  
3 arrangement of Fig. 9A in that the latter arrangement  
4 requires the pipe or casing 200 to be positively held  
5 up (to avoid dropping down the well out of its intended  
6 position) until joined to the upper pipe or casing as  
7 in Fig. 9B, whereas in the Fig. 12A arrangement the  
8 casing hanger allows the inner/lower casing 200 to be  
9 lowered into position and then released without the  
10 possibility of dropping out of position prior to the  
11 two casings being conjoined by the profiling tool, as  
12 depicted in Fig. 12B.

13 Referring now to Figs. 13A & 13B, these schematically  
14 depict another optional modification of the Fig. 9  
15 conjoining procedure in order to achieve a superior  
16 resistance to post-conjunction separation. As depicted  
17 in Fig. 13A, the modification consists of initially  
18 forming the bore (inner surface) of the second (outer)  
19 pipe or casing 202 with two circumferentially extending  
20 grooves 214 each having a width which reduces with  
21 increasing depth. As depicted in Fig. 13B, when the  
22 two pipes or casings 200 and 202 have been conjoined by  
23 the profiling tool (as detailed with respect to Figs.  
24 9A & 9B), the first (inner) pipe or casing 200 will  
25 have been plastically deformed into the grooves 214,  
26 thereby increasing the interlocking of the conjoined  
27 pipes or casings and extending their resistance to  
28 post-conjunction separation. While two grooves 214 are  
29 shown in Figs. 13A & 13B by way of example, this  
30 procedure can in suitable circumstances be carried with  
31 one such groove, or with three or more such grooves.  
32 While each of the grooves 214 has been shown with a  
33 preferred trapezoidal cross-section, other suitable  
34 groove cross-sections can be substituted.

1     The superior joint strength of the Fig. 13 arrangement  
2     can be combined with the superior sealing function of  
3     the Fig. 11 arrangement, as shown in Fig. 14. Fig. 14A  
4     schematically depicts the pre-jointing configuration,  
5     in which the exterior of the first (inner) pipe or  
6     casing 200 is fitted with a longitudinally spaced pair  
7     of circumferentially extending and part-recessed  
8     ductile metal rings 208, while the bore (inner surface)  
9     of the second (outer) pipe or casing 202 is formed with  
10    two circumferentially extending grooves 214 each having  
11    a width which reduces with increasing depth. The  
12    longitudinal spacing of the two grooves 214 is  
13    substantially the same as the longitudinal spacing of  
14    the seal rings 208. When the two pipes or casings are  
15    conjoined by use of the profiling tool (as  
16    schematically depicted in Fig. 14B), the first (inner)  
17    pipe or casing 200 is not only plastically deformed  
18    into the corresponding grooves 214 (as in Fig. 13B),  
19    but the metal rings 208 are crushed into the bottoms of  
20    these grooves 214 thereby to form high grade metal-to-  
21    metal seals.

22    In the arrangements of Figs. 9 - 14, it is assumed that  
23    the second (outer) pipe or casing 202 undergoes little  
24    or no permanent deformation, which may either be due to  
25    the outer pipe or casing 202 being inherently rigid  
26    compared to the first (inner) pipe or casing 200, or be  
27    due to the outer pipe or casing being rigidly backed  
28    (e.g. by cured concrete filling the annulus around the  
29    outer pipe or casing 202), or be due to a combination  
30    of these and/or other reasons. Fig. 15 schematically  
31    depicts an alternative situation in which the second  
32    (outer) pipe or casing 202 does not have the previously  
33    assumed rigidity. As schematically depicted in Fig.  
34    15A, the pre-jointing configuration is merely a variant

1 of the previously described pipe-joining arrangements,  
2 in which the exterior of the upper end of the first  
3 (inner) pipe or casing 200 is provided with two part-  
4 recessed metal seal rings 208 (each mounted in a  
5 respective circumferential groove), neither pipe being  
6 otherwise modified from its initial plain tubular  
7 shape. To conjoin the casings 200 and 202, the  
8 profiling tool is operated in a manner which forces the  
9 second (outer) casing 202 through its elastic limit and  
10 into a region of plastic deformation, such that when  
11 the conjoining process is completed, both casings  
12 retain a permanent outward set as depicted in Fig. 15B.

13 In each of the arrangements described with reference to  
14 Figs. 9 - 15, the bore of the first pipe or casing 200  
15 was generally smaller than the bore of the second pipe  
16 or casing 202. However, there are situations where it  
17 would be necessary or desirable that these bores be  
18 about mutually equal following conjoining, and this  
19 requires variation of the previously described  
20 arrangements, as will now be detailed.

21 In the arrangement schematically depicted in Fig. 16A,  
22 the lower end of the second (outer) pipe or casing 202  
23 is pre-formed to have an enlarged diameter, the bore  
24 (inside diameter) of this enlarged end being marginally  
25 greater than the outside diameter of the first (inner)  
26 pipe or casing 200 intended to be conjoined thereto.  
27 The first (inner) pipe or casing 200 has initial  
28 dimensions which are similar or identical to those of  
29 the second pipe or casing 202 (other than for the  
30 enlarged end of the pipe or casing 202). Following use  
31 of the profiling tool to expand the overlapping ends of  
32 the two pipes or casings, both bores have about the  
33 same diameter (as depicted in Fig. 16B) which has

1 certain advantages (e.g. a certain minimum bore at  
2 depth in a well no longer requires a larger or much  
3 larger bore at lesser depth in the well). While  
4 surface-level pipes can be extended in this manner  
5 without difficulties in adding extra lengths of pipe,  
6 special techniques may be necessary for feeding  
7 successive lengths of casing to downhole locations when  
8 extending casing in a downhole direction. (One  
9 possible solution to this requirement may be provide  
10 successive lengths of casing with a reduced diameter,  
11 and to expand the entire length of each successive  
12 length of casing to the uniform bore of previously  
13 installed casing, this being achievable by further  
14 aspects of the invention to be subsequently described  
15 by way of example with reference to Figs. 20 et seq).

16 A modification of the procedure and arrangement of Fig.  
17 16 is schematically depicted in Fig. 17 wherein the end  
18 of the outer pipe or casing is not pre-formed to an  
19 enlarged diameter (Fig. 17A). It is assumed in this  
20 case that the profiling tool is capable of exerting  
21 sufficient outward force through its rollers as to be  
22 capable of sufficiently extending the diameter of the  
23 outer pipe or casing simultaneously with the diametral  
24 extension of the inner pipe or casing during forming of  
25 the joint (Fig. 17B).

26 As well as conjoining pipes or casings, the profiling  
27 tool in accordance with the invention can be utilised  
28 for other useful purposes such as will now be detailed  
29 with reference to Figs. 18 and 19.

30 In the situation schematically depicted in Fig. 18, a  
31 riser 220 has a branch 222 which is to be blocked off  
32 while continuing to allow free flow of fluid along the

1       riser 220. To meet this requirement, a sleeve 224 is  
2       placed within the riser 220 in position to bridge the  
3       branch 222. The sleeve 224 initially has an external  
4       diameter which is just sufficiently less than the  
5       internal diameter of the riser 220 as to allow the  
6       sleeve 224 to be passed along the riser to its required  
7       location. Each end of the sleeve 224 is provided with  
8       external seals 226 of any suitable form, e.g. the seals  
9       described with reference to Fig. 11. When the sleeve  
10      224 is correctly located across the branch 222, a  
11      profiling tool (not shown in Fig. 18) is applied to  
12      each end of the sleeve 224 to expand the sleeve ends  
13      into mechanically anchoring and fluid-sealing contact  
14      with the bore of the riser 220, thus permanently  
15      sealing the branch (until such time as the sleeve may  
16      be milled away or a window may be cut through it).

17     Fig. 19 schematically depicts another alternative use  
18     of the profiling tool in accordance with the invention,  
19     in which a valve requires to be installed within plain  
20     pipe or casing 240 (i.e. pipe or casing free of landing  
21     nipples or other means of locating and anchoring  
22     downhole equipment). A valve 242 of a size to fit  
23     within the pipe or casing 240 has a hollow tubular  
24     sleeve 244 welded or otherwise secured to one end of  
25     the valve. The sleeve 244 initially has an external  
26     diameter which is just sufficiently less than the  
27     internal diameter of the pipe or casing 240 as to allow  
28     the mutually attached valve 242 and sleeve 244 to  
29     pass down the pipe or casing 240 to the required  
30     location. The end of the sleeve 244 opposite to the  
31     end attached to the valve 242 is provided with external  
32     seals 246 of any suitable form, e.g. the seals  
33     described with reference to Fig. 11. When the valve  
34     242 is correctly located where it is intended to be

1       installed, a profiling tool (not shown in Fig. 19) is  
2       applied to the end of the sleeve opposite the valve 242  
3       to expand that end of the sleeve 244 into mechanically  
4       anchoring and fluid-sealing contact with the bore of  
5       the pipe or casing 240. An optional modification of  
6       the Fig. 19 arrangement is to attach an expandable  
7       sleeve to both sides of the valve such that the valve  
8       can be anchored and sealed on either side instead of  
9       one side only as in Fig. 19.

10      Turning now to Fig. 20, this illustrates a side  
11     elevation of an embodiment of expansion tool 300 in  
12     accordance with the present invention. The expansion  
13     tool 300 is an assembly of a primary expansion tool 302  
14     and a secondary expansion tool 304, together with a  
15     connector sub 306 which is not essential to the  
16     invention but which facilitates mechanical and  
17     hydraulic coupling of the expansion tool 300 to the  
18     downhole end of a drillstring (not shown) or to the  
19     downhole end of coiled tubing (not shown). The primary  
20     expansion tool 302 is shown separately and to an  
21     enlarged scale in Fig. 21 (and again, in exploded view,  
22     in Fig. 21A). The expansion tool 300 is shown in  
23     longitudinal section in Fig. 22, the primary expansion  
24     tool 302 is shown separately in longitudinal section in  
25     Fig. 23, and the secondary expansion tool 304 is shown  
26     separately in an exploded view in Fig. 24.

27      From Figs. 20 - 24 it will be seen that the general  
28     form of the primary expansion tool 302 is that of a  
29     roller tool externally presenting a conical array of  
30     four tapered rollers 310 tapering towards an imaginary  
31     point (not denoted) ahead of the leading end of the  
32     expansion tool 300, i.e. the right end of the tool 300  
33     as viewed in Figs. 20 & 21. As may be more clearly

1 seen in Figs. 21A, 22, & 23, the rollers 310 run on a  
2 conical race 312 integrally formed on the surface of  
3 the body of the primary expansion tool 302, the rollers  
4 being constrained for true tracking by a  
5 longitudinally slotted cage 314. An end retainer 316  
6 for the rollers 310 is secured on the screw-threaded  
7 leading end 318 of the primary expansion tool 302 by  
8 means of a ring nut 320. The trailing end 322 of the  
9 primary expansion tool 302 is screw-threaded into the  
10 leading end 106 of the secondary expansion tool 304 to  
11 form the composite expansion tool 300. Functioning of  
12 the primary expansion tool 300 will be detailed  
13 subsequently.

14 The secondary expansion tool 304 is substantially  
15 identical to the previously detailed profiling tool 100  
16 (except for one important difference which is described  
17 below), and accordingly those parts of the secondary  
18 expansion tool 304 which are the same as corresponding  
19 parts of the profiling tool 100 (or which are obvious  
20 modifications thereof) are given the same reference  
21 numerals. The important difference in the secondary  
22 expansion tool 304 with respect to the profiling tool  
23 100 is that the rotation axes of the rollers 116 are no  
24 longer exactly parallel to the longitudinal axis of the  
25 tool, but are skewed such that each individual roller  
26 rotation axis is tangential to a respective imaginary  
27 helix, though making only a small angle with respect to  
28 the longitudinal direction (compare Fig. 24 with Fig.  
29 4). As particularly shown in Figs. 20 and 24, the  
30 direction (or "hand") of the skew of the rollers 116 in  
31 the secondary expansion tool 304 is such that the  
32 conventional clockwise rotation of the tool (as viewed  
33 from the uphole end of the tool, i.e. the left end as  
34 viewed in Figs. 20 & 22) is such as to induce a

1 reaction against the bore of the casing (not shown in  
2 Figs. 20 - 24) which tends not only to rotate the tool  
3 300 around its longitudinal axis but also to advance  
4 the tool 300 in a longitudinal direction, i.e. to drive  
5 the tool 300 rightwards as viewed in Figs. 20 & 22.  
6 (The use of skewed bore-contacting rollers to cause a  
7 rotating downhole tool to drive itself along a casing  
8 is detailed in the afore-mentioned WO93/24728-A1).

9 In use of the expansion tool 300 to expand casing (not  
10 shown) previously deployed to a selected downhole  
11 location in a well, the tool 300 is lowered on a  
12 drillstring (not shown) or coiled tubing (not shown)  
13 until the primary expansion tool 302 at the leading end  
14 of the tool 300 engages the uphole end of the  
15 unexpanded casing. The core of the tool 300 is  
16 pressurised to force the roller-carrying pistons 120  
17 radially outwards and hence to force the rollers 116  
18 into firm contact with the casing bore. The tool 300  
19 is simultaneously caused to rotate clockwise (as viewed  
20 from its uphole end) by any suitable means (e.g. by  
21 rotating the drillstring (if used), or by actuating a  
22 downhole mud motor (not shown) through which the tool  
23 300 is coupled to the drillstring or coiled tubing),  
24 and this rotation combines with the skew of the rollers  
25 116 of the secondary tool 304 to drive the tool 300 as  
26 a whole in the downhole direction. The conical array  
27 of rollers 310 in the primary expansion tool 302 forces  
28 its way into the uphole end of the unexpanded casing  
29 where the combination of thrust (in a downhole  
30 direction) and rotation rolls the casing into a conical  
31 shape that expands until its inside diameter is just  
32 greater than the maximum diameter of the array of  
33 rollers 310 (i.e. the circumscribing diameter of the  
34 array of rollers 310 at its upstream end). Thereby the

1 primary expansion tool 302 functions to bring about the  
2 primary or initial expansion of the casing.

3 The secondary expansion tool 304 (which is immediately  
4 uphole of the primary expansion tool 302) is internally  
5 pressurised to a pressure which not only ensures that  
6 the rollers 116 contact the casing bore with sufficient  
7 force as to enable the longitudinal traction force to  
8 be generated by rotation of the tool about its  
9 longitudinal axis but also forces the pistons 120  
10 radially outwards to an extent that positions the  
11 piston-carried rollers 116 sufficiently radially  
12 distant from the longitudinal axis of the tool 304  
13 (substantially coincident with the centreline of the  
14 casing) as to complete the diametral expansion of the  
15 casing to the intended final diameter of the casing.  
16 Thereby the secondary expansion tool 304 functions to  
17 bring about the secondary expansion of the casing.  
18 (This secondary expansion will normally be the final  
19 expansion of the casing, but if further expansion of  
20 the casing is necessary or desirable, the expansion  
21 tool 300 can be driven through the casing again with  
22 the rollers 116 of the secondary expansion tool set at  
23 a greater radial distance from the longitudinal axis of  
24 the tool 304, or a larger expansion tool can be driven  
25 through the casing). While the primary expansion tool  
26 302 with its conical array of rollers 310 is preferred  
27 for initial expansion of casing, the secondary  
28 expansion tool 304 with its radially adjustable rollers  
29 has the advantage that the final diameter to which the  
30 casing is expanded can be selected within a range of  
31 diameters. Moreover, this final diameter can not only  
32 be adjusted while the tool 304 is static but can also  
33 be adjusted during operation of the tool by suitable  
34 adjustment of the extent to which the interior of the

1      tool 304 is pressurised above the pressure around the  
2      outside of the tool 304. This feature also gives the  
3      necessary compliance to deal with variances in wall  
4      thickness

5      Fig. 25 is a longitudinal section of a primary  
6      expansion tool 402 which is a modified version of the  
7      primary expansion tool 302 (detailed above with  
8      reference to Figs. 20 - 24). Components of the tool  
9      402 which correspond to components of the tool 302 are  
10     given the same reference numeral except that the  
11     leading "3" is replaced by a leading "4". The tool 402  
12     is essentially the same as the tool 302 except that the  
13     rollers 410 are longer than the rollers 310, and the  
14     conical race 412 has a cone angle which is less than  
15     the cone angle of the race 312 (i.e. the race 412  
16     tapers less and is more nearly cylindrical than the  
17     race 312). As shown in Fig. 25, the trailing (uphole)  
18     end of the tool 402 is broken away. For details of  
19     other parts of the tool 402, reference should be made  
20     to the foregoing description of the tool 302. In  
21     contrast to Figs. 20 - 24, Fig. 25 also shows a  
22     fragment of casing 480 which is undergoing expansion by  
23     the tool 402.

24     Fig. 26 is a longitudinal section of a primary  
25     expansion tool 502 which is a further-modified version  
26     of the primary expansion tool 302. Components of the  
27     tool 502 which correspond to components of the tool 302  
28     are given the same reference numeral except that the  
29     leading "3" is replaced by a leading "5". The tool 502  
30     is identical to the tool 402 except that the rollers  
31     510 have a length which is somewhat less than the  
32     length of the rollers 410. This reduced length allows  
33     the rollers 510 some longitudinal freedom within their

1       windows in the cage 514. Consequently, although  
2       expansion operation of the primary expansion tool 502  
3       is essentially identical to operation of the primary  
4       expansion tool 410 (and similar to operation of the  
5       primary expansion tool 310 except for functional  
6       variations occasioned by the different conicities of  
7       the respective races), reversal of longitudinal thrust  
8       on the tool 502 (i.e. pulling the tool 502 uphole  
9       instead of pushing the tool 502 downhole) will cause or  
10      allow the rollers 510 to slide along the conical race  
11      512 in the direction of its reducing diameter, thus  
12      allowing the rollers 510 radially to retract from the  
13      casing bore as illustrated in Fig. 26. Such roller  
14      retraction frees the tool 502 from the casing 480 and  
15      permits free withdrawal of the tool 502 in an uphole  
16      direction whereas the non-retracting rollers 410 of the  
17      tool 402 might possibly jam the tool 402 within the  
18      casing 480 in the event of attempted withdrawal of the  
19      tool 402.

20     Turning now to Fig. 27, this is a simplified  
21     longitudinal elevation of a casing expander assembly  
22     600 for use in downhole expansion of a solid, slotted  
23     or imperforate metal tube 602 within a casing 604 which  
24     lines a well. The casing expander assembly 600 is a  
25     three-stage expansion tool which is generally similar  
26     (apart from the number of expansion stages) to the two-  
27     stage expansion tool 300 described above with reference  
28     to Figs. 20 - 24.

29     In order from its leading (downhole) end, the expander  
30     assembly 600 comprises a running/guide assembly 610, a  
31     first-stage conical expander 612, an inter-stage  
32     coupling 614, a second-stage conical expander 616, a  
33     further inter-stage coupling 618, and a third-stage

1       cylindrical expander 620.

2       The first-stage conical expander 612 comprises a  
3       conical array of tapered rollers which may be the same  
4       as either one of the primary expansion tools 302 or  
5       402, or which differs therefrom in respect of the  
6       number of rollers and/or in respect of the cone angles  
7       of the rollers and their race.

8       The second-stage conical expander 616 is an enlarged-  
9       diameter version of the first-stage conical expander  
10      612 dimensioned to provide the intermediate expansion  
11      stage of the three-stage expansion assembly 600. The  
12      diameter of the leading (narrow) end of the second-  
13      stage expander 616 (the lower end of the expander 616  
14      as viewed in Fig. 27) is marginally less than the  
15      diameter of the trailing (wide) end of the first-stage  
16      expander 612 (the upper end of the expander 612 as  
17      viewed in Fig. 27) such that the second-stage expander  
18      616 is not precluded from entering initially expanded  
19      tube 602 resulting from operation of the first-stage  
20      expander 612.

21      The third-stage expander 620 is a generally cylindrical  
22      expander which may be similar either to the profiling  
23      tool 100 or to the secondary expansion tool 304.  
24      (Although the rollers of the third-stage expander 620  
25      may be termed "cylindrical" in order to facilitate  
26      distinction over the conical rollers of the first-stage  
27      and second-stage expanders 612 & 616, and although in  
28      certain circumstances such so-called "cylindrical"  
29      rollers may in fact be truly cylindrical, the rollers  
30      of the cylindrical expander will usually be barrelled  
31      to avoid excessive end stresses). The rollers of the  
32      third-stage expander 620 will normally be radially

1 extended from the body of the expander 620 by an extent  
2 that the third-stage expander 620 rolls the tube 602  
3 into its final extension against the inside of casing  
4 604, such that no further expansion of the tube 602 is  
5 required in the short term.

6 The inter-stage couplings 614 and 618 can be  
7 constituted by any suitable arrangement that  
8 mechanically couples the three expander stages, and  
9 (where necessary or desirable) also hydraulically  
10 couples the stages.

11 The rollers of the third-stage expander 620 may be  
12 skewed such that rotation of the assembly 600 drives  
13 the assembly in a downhole direction; alternatively,  
14 the rollers may be unskewed and forward thrust on the  
15 expanders be provided by suitable weights, e.g. by  
16 drill collars 630 immediately above the assembly 600.  
17 Where the third-stage rollers are skewed, drill collars  
18 can be employed to augment the downhole thrust provided  
19 by rotation of the assembly 600.

20 As depicted in Fig. 27, the three-stage expander  
21 assembly 600 is suspended from a drillstring 640 which  
22 not only serves for transmitting rotation to the  
23 assembly 600 but also serves for transmitting hydraulic  
24 fluid under pressure to the assembly 600 for radial  
25 extension of the third-stage rollers, for cooling the  
26 assembly 600 and newly deformed tube 602, and for  
27 flushing debris out of the work region.

28 In suitable circumstances, the drillstring 640 may be  
29 substituted by coiled tubing (not shown) of a form  
30 known per se.

1 Turning now to Fig. 28 (which is divided into three  
2 mutually related Figs. 28A, 28B, & 28C), these  
3 illustrate a primary expansion tool 702 which may be  
4 summarised as being the primary expansion tool 402  
5 (Fig. 25) with hard steel bearing balls 710 substituted  
6 for the rollers 410. Each of the balls 710 runs in a  
7 respective circumferential groove 712, and is located  
8 for proper tracking by a suitably perforated cage 714.  
9 As with the tool 402, the cage 714 is retained by a  
10 retainer 716 secured on the screw-threaded leading end  
11 718 of the tool 702 by means of a ring nut 720.  
12 Operation of the tool 702 is functionally similar to  
13 operation of the tool 402, as is illustrated by the  
14 expansion effect of the tool 702 on casing 480.

15 The primary expansion tool 702 as shown in Figs. 28A -  
16 could be modified by the substitution of the series  
17 of circumferential ball tracks 712 with a single spiral  
18 track (not shown) around which the balls 710 would  
19 circulate at ever-increasing radii to create the  
20 requisite expansion forces on the casing. At the point  
21 of maximum radius, the balls 710 would be recirculated  
22 back to the point of minimum radius (near the leading  
23 end of the tool 702, adjacent the retainer 716) by  
24 means of a channel (not shown) formed entirely within  
25 the central body of the tool 702 in a form analogous to  
26 a recirculating ball-screw (known per se).

27 Figs. 29A & 29B illustrate a modification 802 of the  
28 ball-type expansion primary expansion tool 702 of Fig.  
29 28 analogous to the Fig. 26 modification 502 of the  
30 Fig. 25 roller-type primary expansion tool 402. In the  
31 modified ball-type primary expansion tool 802, the hard  
32 steel bearing balls 810 run in longitudinally-extending  
33 grooves 812 instead of the circumferential grooves 712

1 of the tool 702. The ball-guiding perforations in the  
2 cage 814 are longitudinally extended into slots which  
3 allow individual balls 810 to take up different  
4 longitudinal positions (and hence different effective  
5 radii) according to whether the tool 802 is being  
6 pushed downhole (Fig. 28A) or being pulled uphole (Fig.  
7 28B). In the latter case, the balls 810 are relieved  
8 from pressure on the surrounding casing 480 and thereby  
9 obviate any risk of the tool 802 becoming jammed in  
10 partly-expanded casing.

11 In the profiling and expansion tools with controllably  
12 displaceable rollers as previously described, e.g. with  
13 reference to Figs. 4 and 24, the ability to obtain and  
14 to utilise hydraulic pressure may place practical  
15 limits on the forces which can be exerted by the  
16 rollers. Fig. 30 illustrates a roller-type  
17 expansion/profiling tool 900 which utilises a  
18 mechanical force-multiplying mechanism to magnify a  
19 force initially produced by controlled hydraulic  
20 pressure, and to apply the magnified force to  
21 profiling/expanding rollers 902. Each of the plurality  
22 of rollers 902 (only two being visible in Fig. 30) has  
23 a longitudinally central portion which is near-  
24 cylindrical and slightly barreled (i.e. slightly  
25 convex), bounded on either side by end portions which  
26 are conical, both end portions tapering from  
27 conjunction with the central portion to a minimum  
28 diameter at each end. Rotation of each roller 902  
29 about a respective rotation axis which is parallel to  
30 the longitudinal axis of the tool 900 and at a  
31 controllably variable radial displacement therefrom is  
32 ensured by a roller-guiding cage 904 of suitable form.

33 The effective working diameter of the tool 900 is

1 dependent on the (normally equal) radial displacements  
2 of the rollers 902 from the longitudinal axis of the  
3 tool 900 (such displacement being shown at a minimum in  
4 Fig. 30). The conical end portions of each roller 902  
5 each run on a respective one of two conical races 906  
6 and 908 whose longitudinal separation determines the  
7 radial displacement of the rollers 902. The conical  
8 races 906 and 908 are coupled for synchronous rotation  
9 but variable separation by means of a splined shaft 910  
10 which is rigid with the upper race 906 and non-  
11 rotatably slidably in the lower race 908. The tool 900  
12 has a hollow core which hydraulically couples through  
13 an upper sub 912 to a drillstring (not shown) which  
14 both selectively rotates the tool 900 within  
15 surrounding casing 990 which is to be profiled/expanded  
16 by the tool 900 and transmits controllable hydraulic  
17 pressure to the core of the tool 900 for controlling  
18 the roller displacement as will now be detailed.

19 The lower end of the tool 900 (with which the lower  
20 race 908 is integral) is formed as hollow cylinder 914  
21 within which a piston 916 is slidably sealed. The  
22 piston 916 is mounted on the lower end of a downward  
23 extension of the shaft 910 which is hollow to link  
24 through the tool core and the drillstring to the  
25 controlled hydraulic pressure. The piston 916 divides  
26 the cylinder 914 into upper and lower parts. The upper  
27 part of the cylinder 914 is linked to the controlled  
28 hydraulic pressure by way of a side port 918 in the  
29 hollow shaft 910, just above the piston 916. The lower  
30 part of the cylinder 914 is vented to the outside of  
31 the tool 900 through a hollow sub 920 which constitutes  
32 the lower end of the tool 900 (and which enables  
33 further components, tools, or drillstring (not shown))  
34 to be connected below the tool 900). Thereby a

1 controllable hydraulic pressure differential can be  
2 selectively created across the piston 916, with  
3 consequent control of the longitudinal separation of  
4 the two roller-supporting conical races 906 and 908  
5 which in turn controls the effective rolling diameter  
6 of the tool 900.

7 While certain modifications and variations of the  
8 invention have been described above, the invention is  
9 not restricted thereto, and other modifications and  
10 variations can be adopted without departing from the  
11 scope of the invention as defined in the appended  
12 claims.

**1 CLAIMS :**

- 2       1. A method of profiling a pipe or other hollow tubular  
3       article, the method comprising the steps of applying a  
4       roller means to a part of the pipe bore selected to be  
5       profiled, translating the roller means across the bore  
6       in a direction including a circumferential component  
7       while applying a force to the roller means in a  
8       radially outwards direction with respect to the  
9       longitudinal axis of the pipe, and continuing such  
10      translation and force application until the pipe is  
11      plastically deformed substantially into the intended  
12      profile.
- 13     2. A method according to claim 1 wherein the  
14     deformation of the pipe is accomplished by radial  
15     compression of the pipe wall, or by circumferential  
16     stretching of the pipe wall, or by a combination of  
17     such radial compression and circumferential stretching.
- 18     3. A method according to claim 1 or claim 2 wherein  
19     said direction is purely circumferential.
- 20     4. A method according to claim 1 or claim 2 wherein  
21     said direction is partly circumferential and partly  
22     longitudinal.
- 23     5. A method according to any preceding claim wherein  
24     said roller means is peripherally profiled to be  
25     complementary to the profile into which the selected  
26     part of the pipe bore is intended to be formed.
- 27     6. A method according to any preceding claim wherein  
28     the selected part of the pipe bore is remote from an  
29     open end of the pipe, and the method comprises the

1 further steps of inserting the roller means into the  
2 open end of the pipe (if the roller means is not  
3 already in the pipe), and transferring the roller means  
4 along the pipe to the selected location.

5

6 7. A method as claimed in claim 6 wherein transfer of  
7 the roller means is accomplished by the step of  
8 actuating traction means coupled to or forming part of  
9 the roller means and effective to apply along-pipe  
10 traction forces to the roller means by reaction against  
11 parts of the pipe bore adjacent the roller means.

12 8. A method of conjoining two pipes or other hollow  
13 tubular articles, said method comprising the steps of  
14 locating one of the two pipes within and longitudinally  
15 overlapping one of the other of the two pipes, applying  
16 roller means to a part of the bore of the inner of the  
17 two pipes at a location where it is intended that the  
18 two pipes be conjoined, translating the roller means  
19 across the bore in a direction including a  
20 circumferential component while applying a radially  
21 outwardly directed force to the roller means, and  
22 continuing such translation and force application until  
23 the inner pipe is plastically deformed into permanent  
24 contact with the outer pipe and is thereby conjoined  
25 thereto.

26 9. A method according to claim 8 wherein said  
27 deformation is accomplished by radial compression of  
28 the pipe wall, or by circumferential stretching of the  
29 pipe wall, or by a combination of such radial  
30 compression and circumferential stretching.

31 10. A method according to claim 8 or claim 9 wherein  
32 said direction is purely circumferential.

- 1        11. A method according to claim 8 or claim 9 wherein  
2        said direction is partly circumferential and partly  
3        longitudinal.
- 4        12. A method according to any of claims 8 to 11 wherein  
5        the location where the pipes are intended to be  
6        conjoined is remote from an accessible end of the bore,  
7        and the method comprises the further steps of inserting  
8        the roller means into the accessible end of the bore  
9        (if the roller means is not already in the bore), and  
10      transferring the roller means to the intended location.
- 11      13. A method according to claim 12 wherein transfer of  
12      the roller means is accomplished by the step of  
13      actuating traction means coupled to or forming part of  
14      the roller means and effective to apply along-bore  
15      traction forces to the roller means by reaction against  
16      parts of the pipe bore adjacent the roller means.
- 17      14. Apparatus for expanding a pipe or other hollow  
18      tubular article, said apparatus comprising roller means  
19      constructed or adapted for rolling deployment against  
20      the bore of the pipe, said roller means comprising at  
21      least one set of individual rollers each mounted for  
22      rotation about a respective rotation axis which is  
23      generally parallel to the longitudinal axis of the  
24      apparatus, the rotation axes of said at least one set  
25      of rollers being circumferentially distributed around  
26      the expansion apparatus and each being radially offset  
27      from the longitudinal axis of the expansion apparatus,  
28      the expansion apparatus being selectively rotatable  
29      around its longitudinal axis.
- 30      15. Apparatus according to claim 14 wherein the  
31      rotation axes of said at least one set of rollers

1 conform to a first regime in which each said rotation  
2 axis is substantially parallel to the longitudinal axis  
3 of the apparatus in a generally cylindrical  
4 configuration.

5 16. Apparatus according to claim 14 wherein the  
6 rotation axes of said at least one set of rollers  
7 conform to a second regime in which each said rotation  
8 axis lies substantially in a respective radial plane  
9 including the longitudinal axis of the apparatus and  
10 the rotation axes each converge substantially towards a  
11 common point substantially on the longitudinal axis of  
12 the apparatus in a generally conical configuration.

13 17. Apparatus according to claim 14 wherein the  
14 rotation axes of said at least one set of rollers  
15 conform to a third regime in which each said rotation  
16 axis is similarly skewed with respect to the  
17 longitudinal axis of the apparatus in a generally  
18 helical configuration which is either non-convergent  
19 (cylindrical) or convergent (conical).

20 18. Apparatus according to any of claims 14 to 17  
21 wherein the apparatus has only a single such set of  
22 rollers.

23 19. Apparatus according to any of claims 14 to 17  
24 wherein the apparatus has a plurality of such sets of  
25 rollers.

26 20. Apparatus according to claim 19 wherein the sets of  
27 rollers conform to two or more different ones of the  
28 three regimes of roller axis alignments defined in  
29 claims 15-17.

- 1        21. Apparatus according to claim 20 wherein the  
2        apparatus has a set of rollers conforming to the second  
3        regime located at leading end of the apparatus and  
4        another set of rollers conforming to the first regime  
5        located elsewhere on the apparatus.
- 6        22. Apparatus according to claim 21 modified by the  
7        addition of a further set of rollers conforming to  
8        third regime with non-convergent axes, this further set  
9        of rollers being utilised for the purpose of applying  
10      traction forces to the apparatus.
- 11      22. Apparatus according to any of claims 14 to 21  
12      wherein the rollers of said apparatus are each mounted  
13      for rotation about its respective rotation axis  
14      substantially without freedom of movement along its  
15      respective rotation axis.
- 16      23. Apparatus according to any of claims 14 to 21  
17      wherein the rollers of said apparatus are each mounted  
18      for rotation about its respective rotation axis with  
19      freedom of movement along its respective rotation axis,
- 20      24. Apparatus according to claim 23 wherein said  
21      rollers have freedom of movement which is constrained  
22      within predetermined limits of movement.
- 23      25. Apparatus for profiling or conjoining pipes or  
24      other hollow tubular articles, said apparatus  
25      comprising roller means and radial urging means  
26      selectively operable to urge the roller means radially  
27      outwards of a longitudinal axis of the apparatus, the  
28      radial urging means causing or allowing the roller  
29      means to move radially inwards towards the longitudinal  
30      axis of the apparatus when the radial urging means is

1 not operated, the roller means comprising a plurality  
2 of individual rollers each mounted for rotation about a  
3 respective rotation axis which is substantially  
4 parallel to the longitudinal axis of the apparatus, the  
5 rotation axes of the individual rollers being  
6 circumferentially distributed around the apparatus and  
7 each said rotation axis being radially offset from the  
8 longitudinal axis of the apparatus, the apparatus being  
9 selectively rotatable around its longitudinal axis to  
10 translate the roller means across the bore of a pipe  
11 against which the roller means is being radially urged.  
12

13 26. Apparatus according to claim 25 wherein the radial  
14 urging means comprises a respective piston on which  
15 each said roller is individually rotatably mounted,  
16 each said piston being slidably sealed in a respective  
17 radially extending bore formed in a body of the  
18 apparatus, a radially inner end of each said bore being  
19 in fluid communication with fluid pressure supply means  
20 selectively pressurisable to operate said radial urging  
21 means.

22 27. Apparatus according to claim 25 wherein the radial  
23 urging means comprises bi-conical race means upon which  
24 each said individual roller rolls in use of the  
25 apparatus, and separation variation means selectively  
26 operable controllably to vary the longitudinal  
27 separation of the two conical races of the bi-conical  
28 race means whereby correspondingly to vary the radial  
29 displacement of each said roller rotation axis from the  
30 longitudinal axis of the apparatus.

31 28. Apparatus according to claim 27 wherein the  
32 separation variation means comprises hydraulic linear  
33 motor means selectively pressurisable to drive one of

1 said two cones longitudinally towards and/or away from  
2 the other said cone.

3 29. A method of expanding an inner pipe into an outer  
4 pipe, said method comprising effecting rolling  
5 compressive yield of the wall of the inner pipe wall to  
6 cause reduction in wall thickness and subsequent  
7 increase in circumference resulting in diameter  
8 increase.

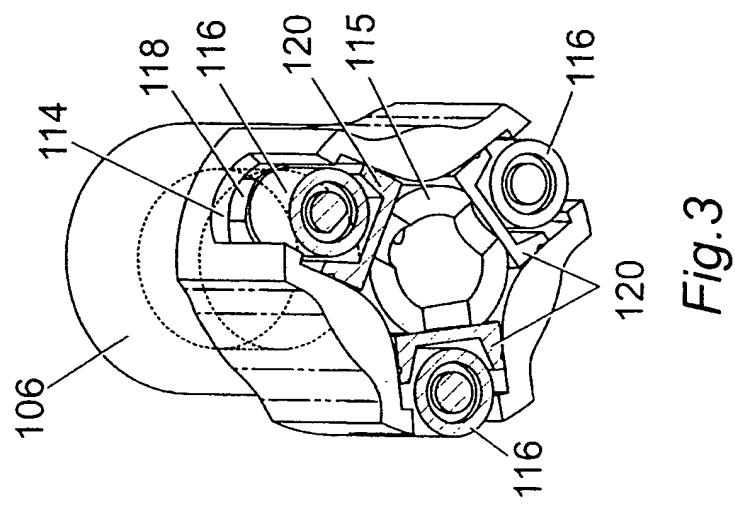
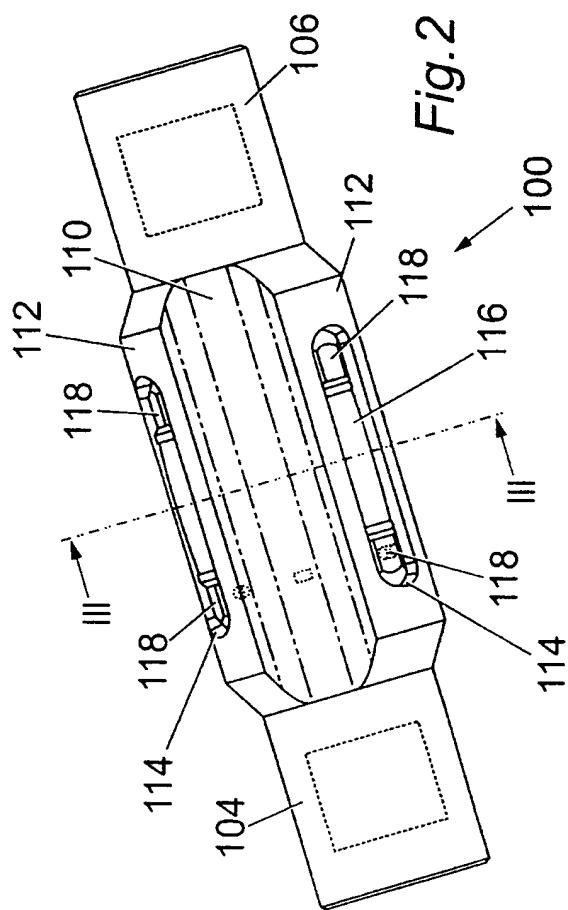
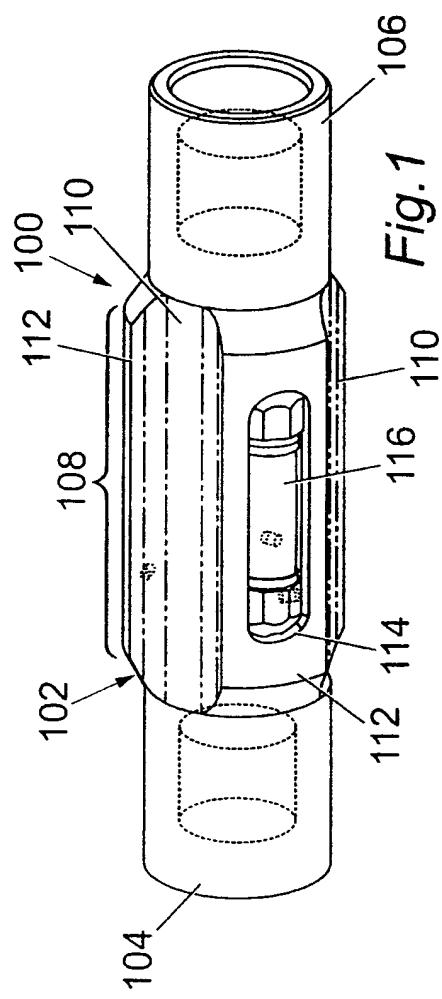
9 30. A method as claimed in Claim 29, wherein the method  
10 generates compressive hoop stress in the inner pipe  
11 resulting in an interference fit of the inner pipe  
12 within the outer pipe.

13 31. A method as claimed in Claim 30, wherein the  
14 resulting interference fit can withstand a high level  
15 of longitudinal force resulting from tensile or  
16 compressive stress.

17 32. A method of creating a high pressure seal between  
18 an inner pipe and an outer pipe by creating a metal to  
19 metal interface between the pipes by effecting rolling  
20 compressive yield of the inner pipe within the outer  
21 pipe.

22 33. A method as claimed in Claim 32, including the  
23 addition of elastomer or ductile metal seals between  
24 the inner pipe and outer pipe.

1 / 25



2 / 25

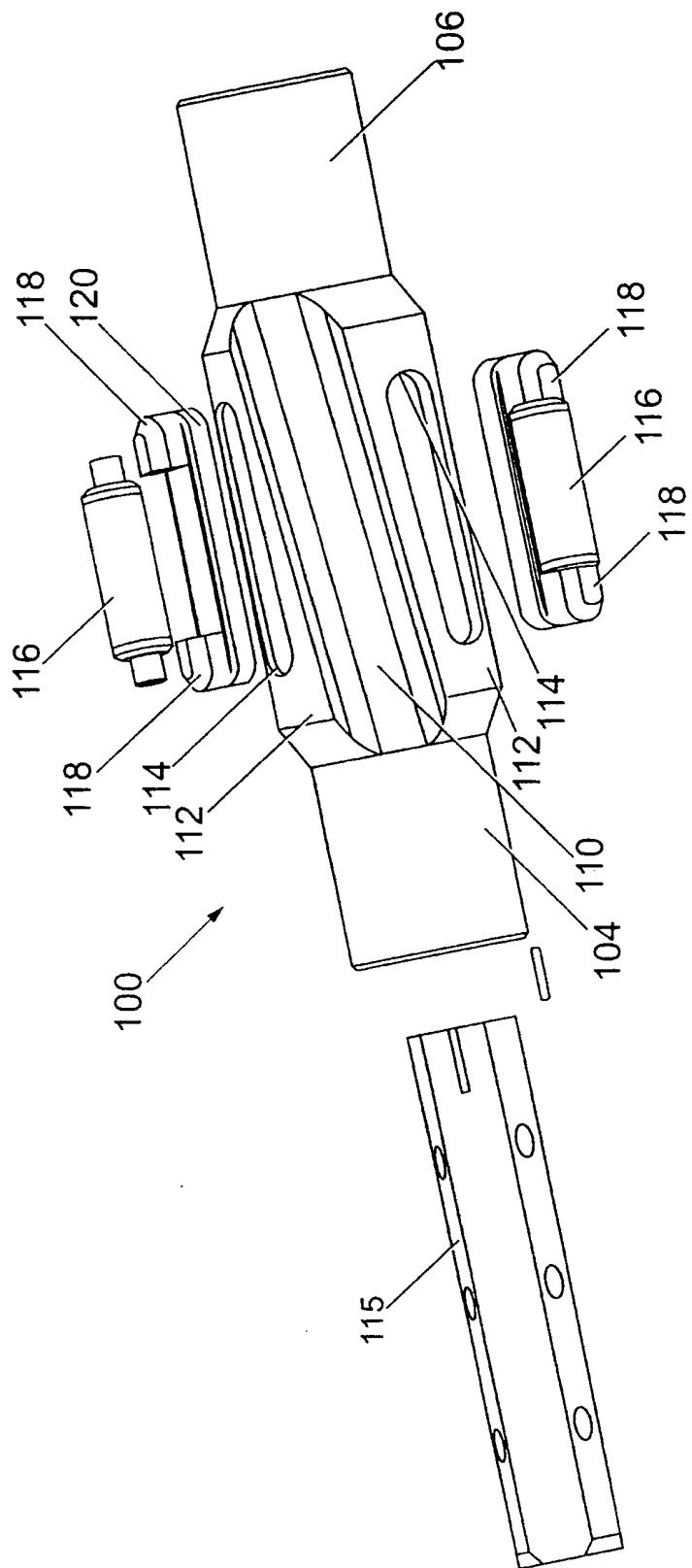


Fig. 4

3 / 25

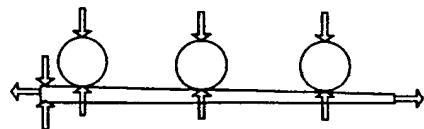
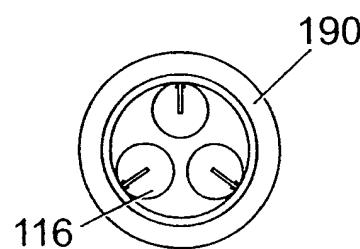
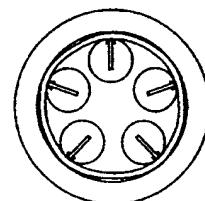
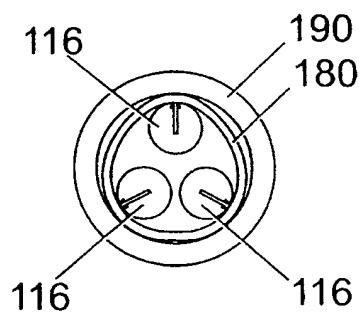
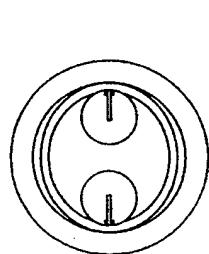
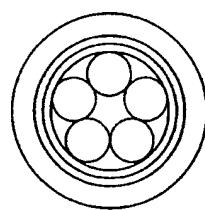
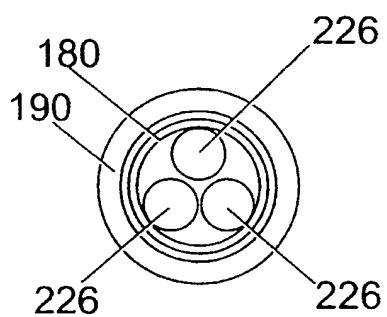
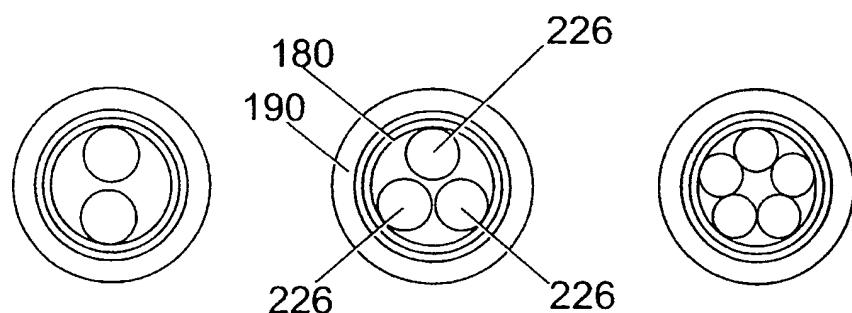


Fig. 6



4 / 25

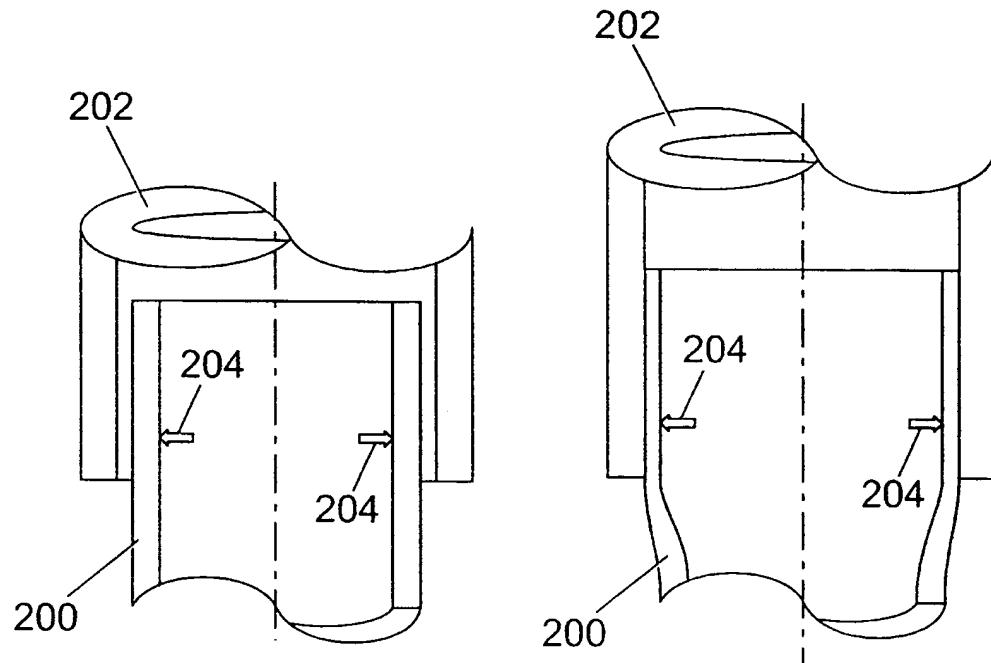
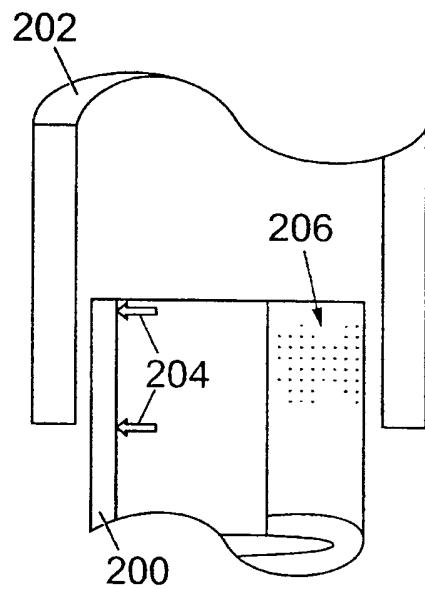


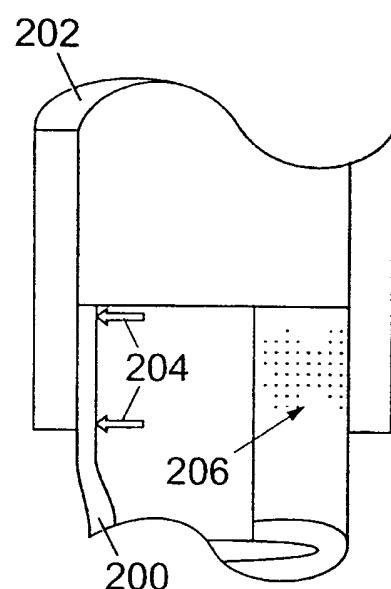
Fig. 9a

Fig. 9b

5 / 25



*Fig. 10a*



*Fig. 10b*

6 / 25

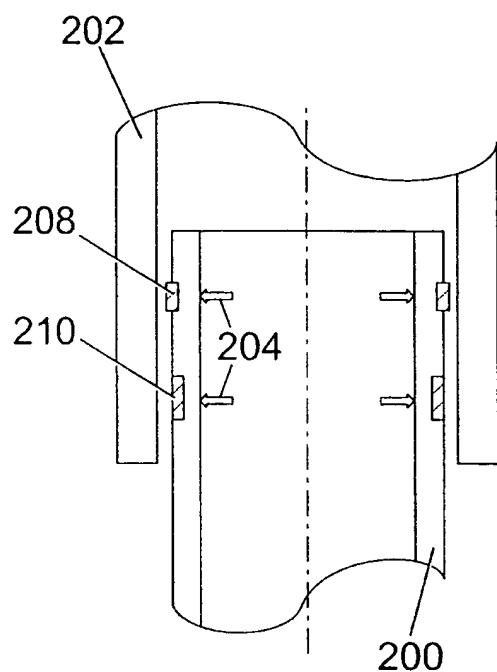


Fig. 11a

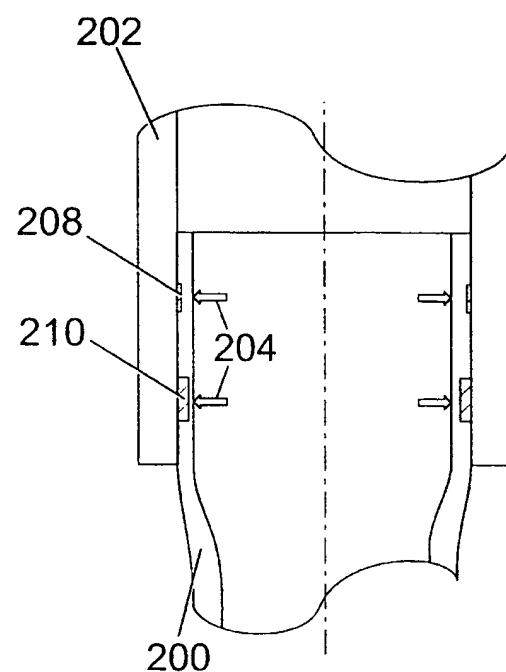


Fig. 11b

7 / 25

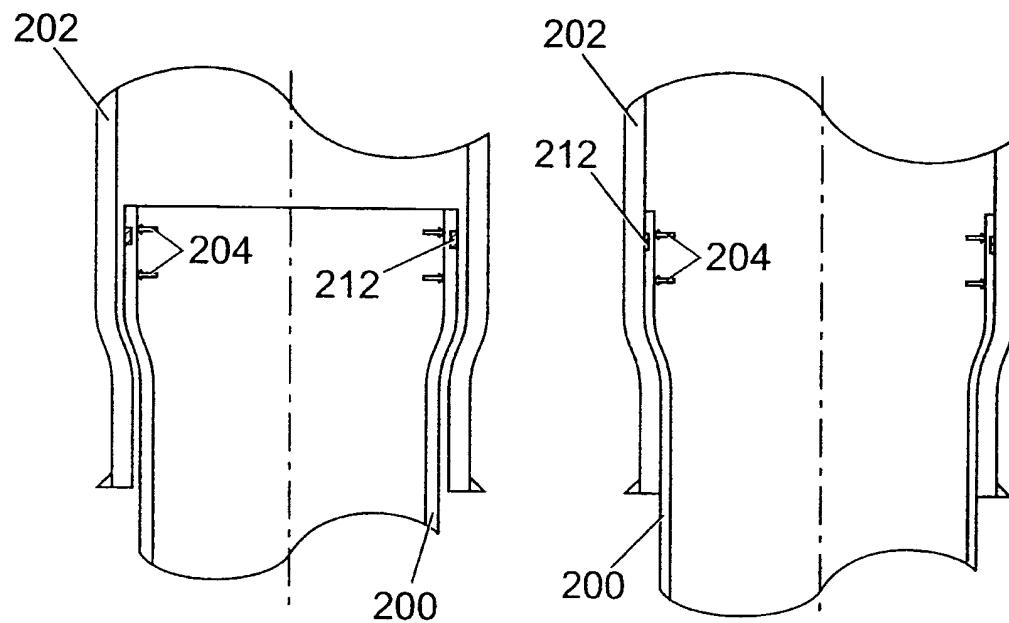


Fig. 12a

Fig. 12b

8 / 25

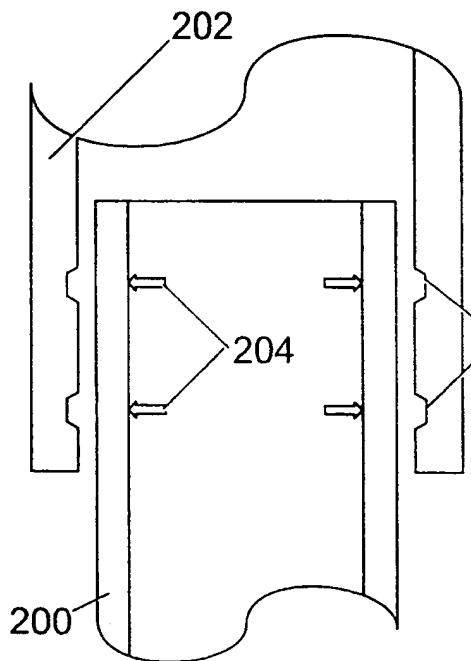


Fig. 13a

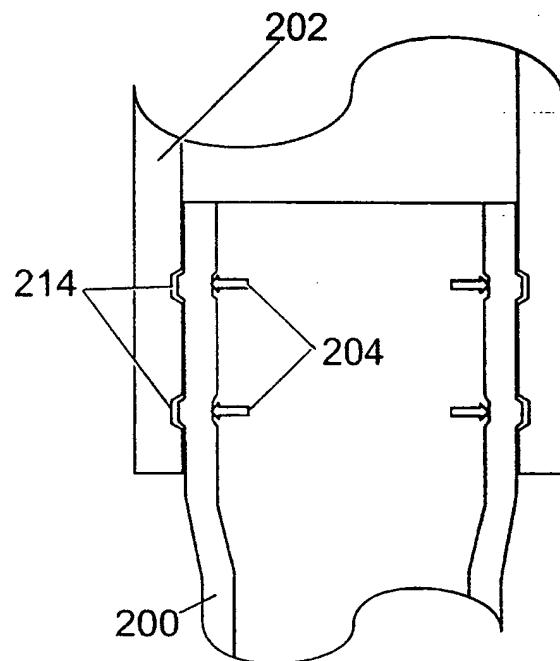


Fig. 13b

9 / 25

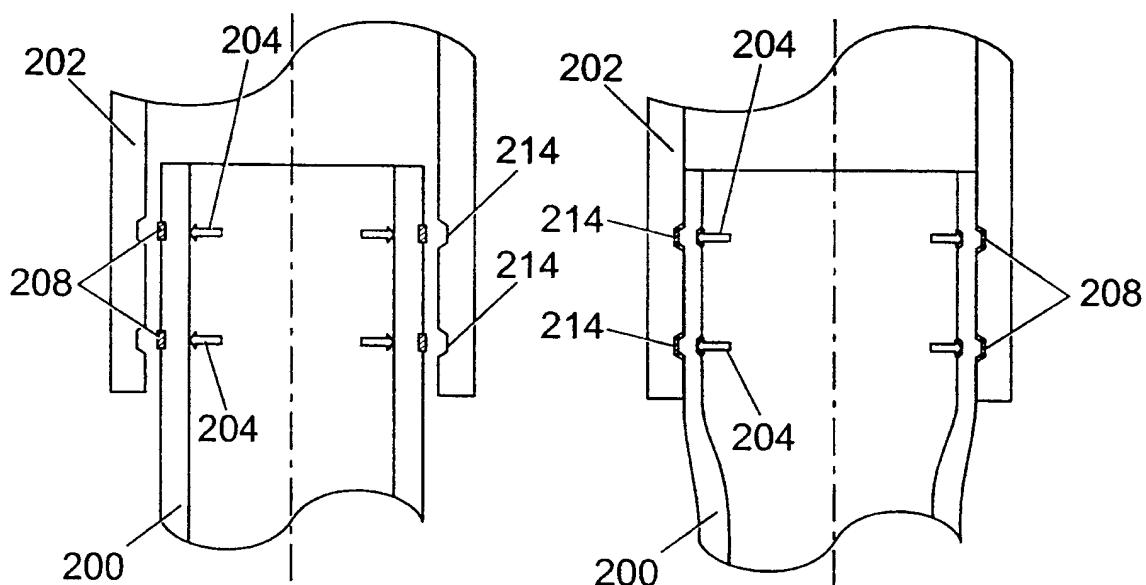


Fig. 14a

Fig. 14b

10 / 25

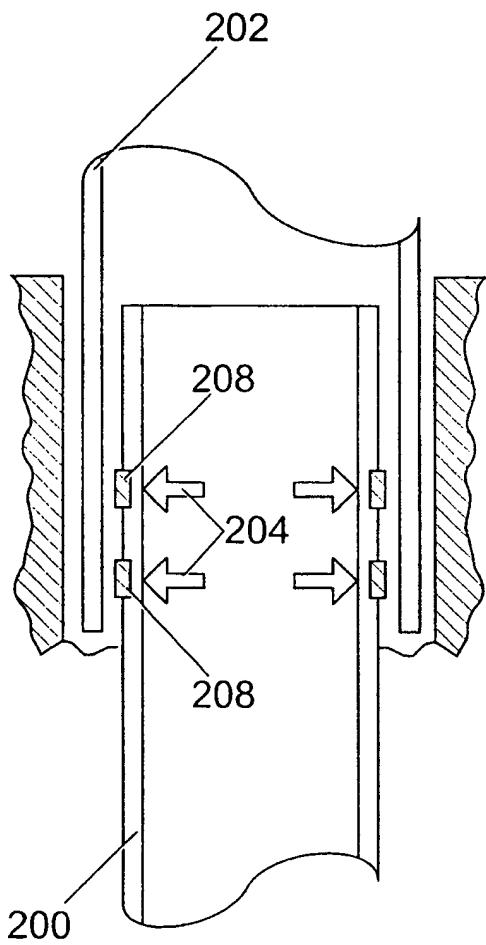


Fig. 15a

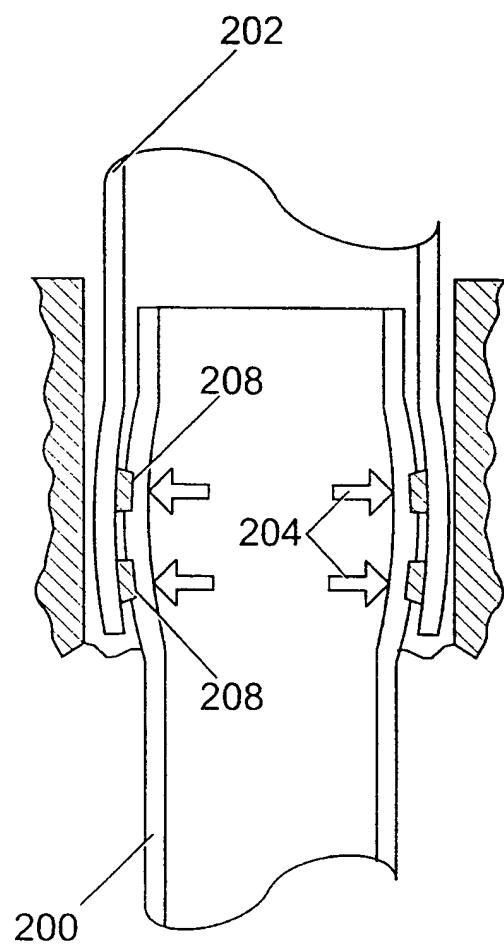
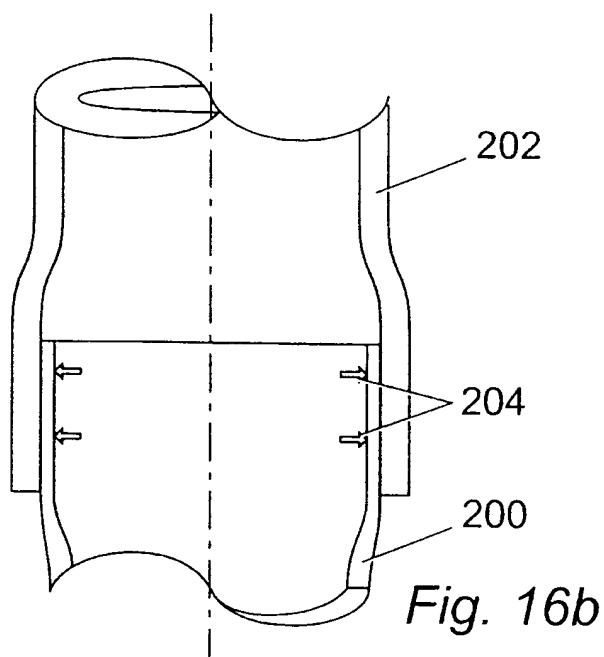
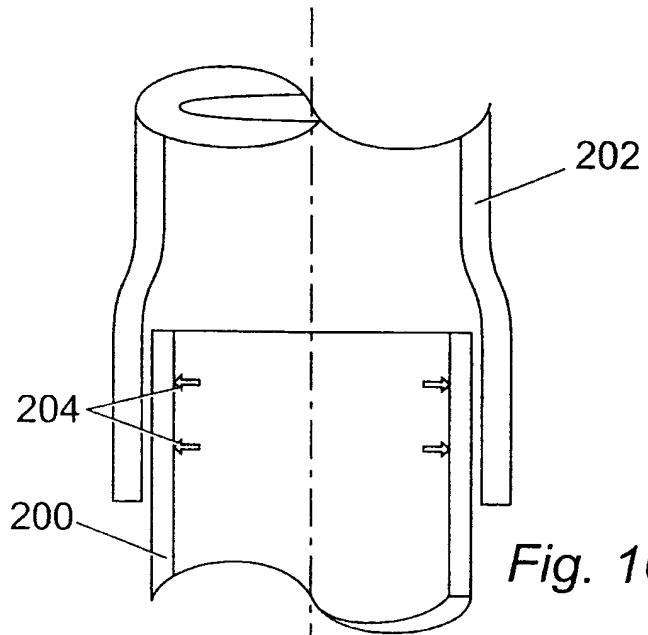


Fig. 15b

11 / 25



12 / 25

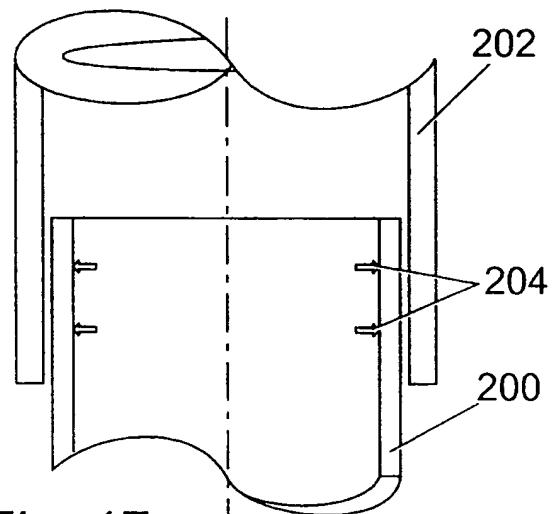


Fig. 17a

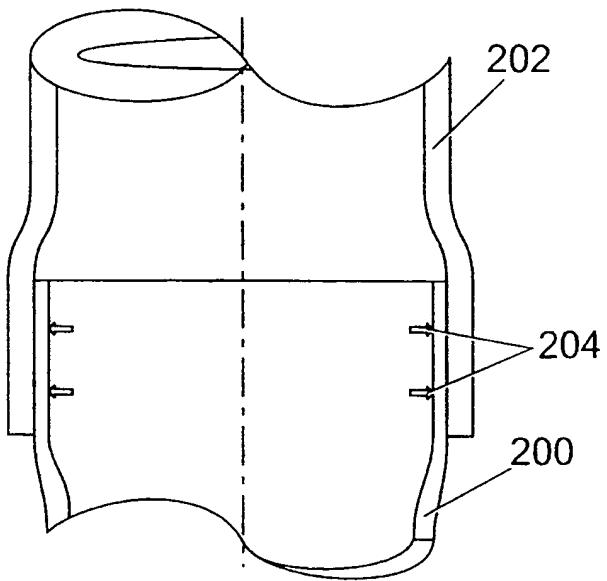
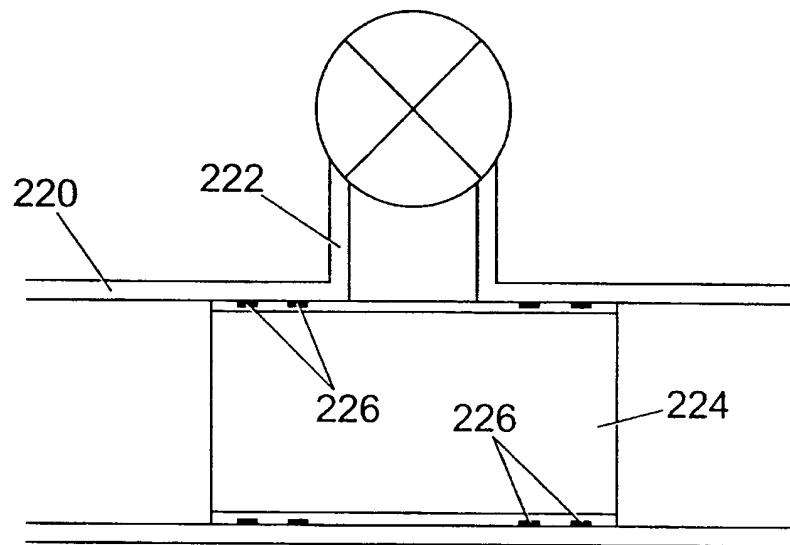
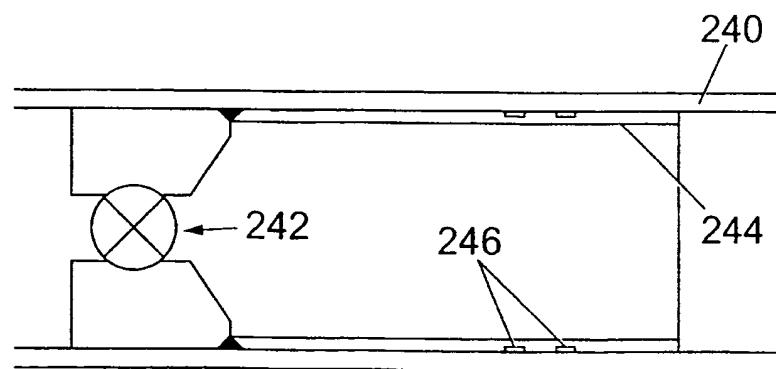


Fig. 17b

13 / 25



*Fig. 18*



*Fig. 19*

14 / 25

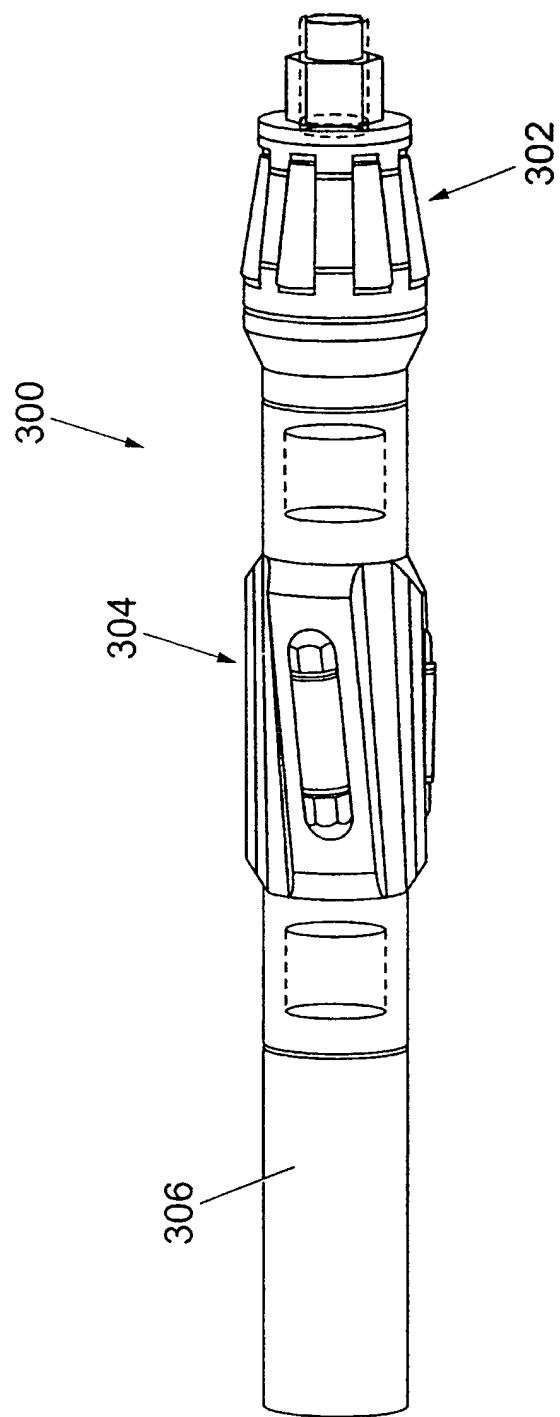


Fig. 20

15 / 25

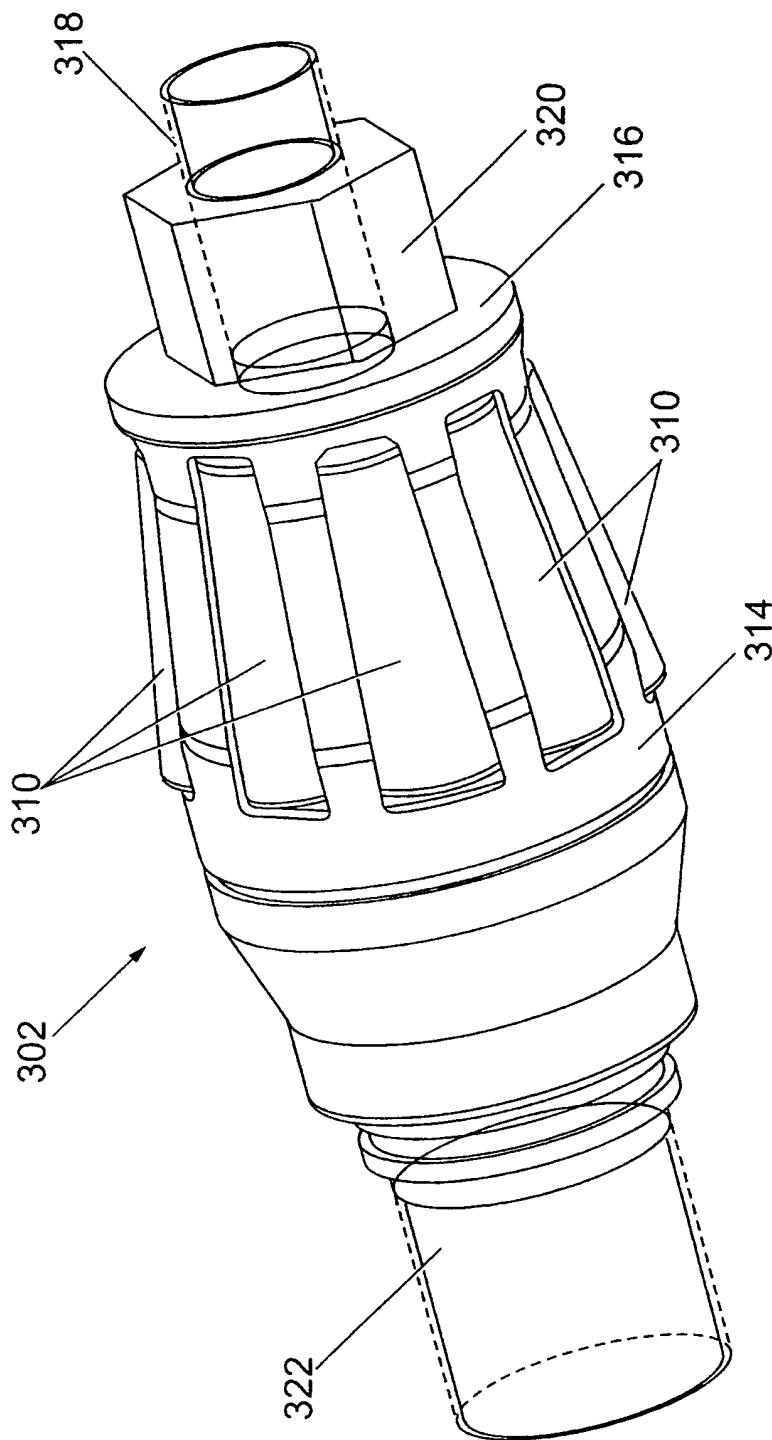


Fig. 21

16 / 25

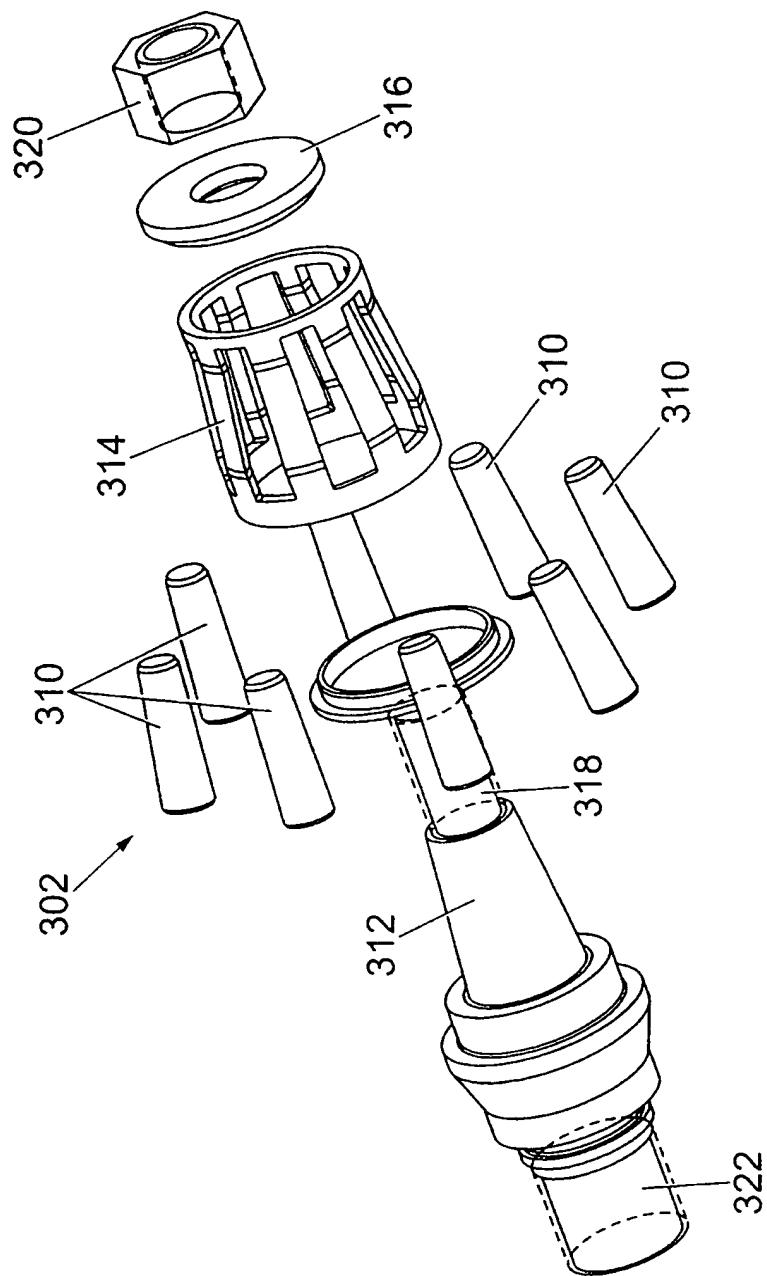
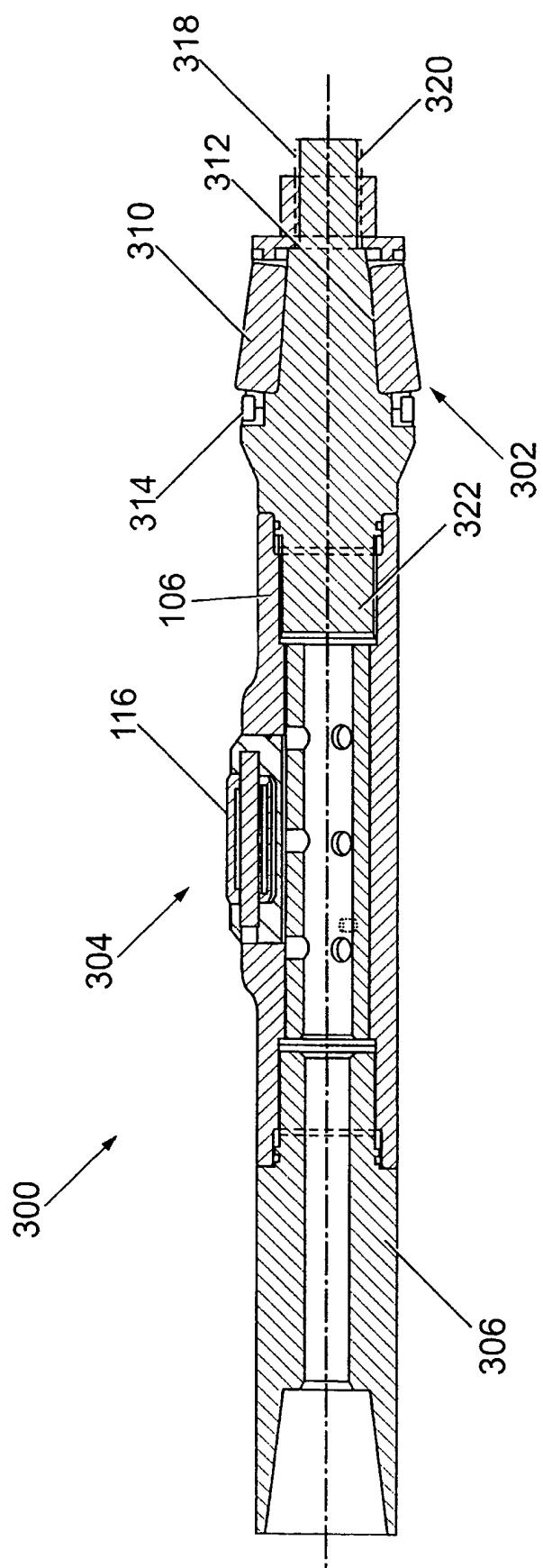


Fig. 21a

17 / 25



SUBSTITUTE SHEET (RULE 26)

Fig. 22

18 / 25

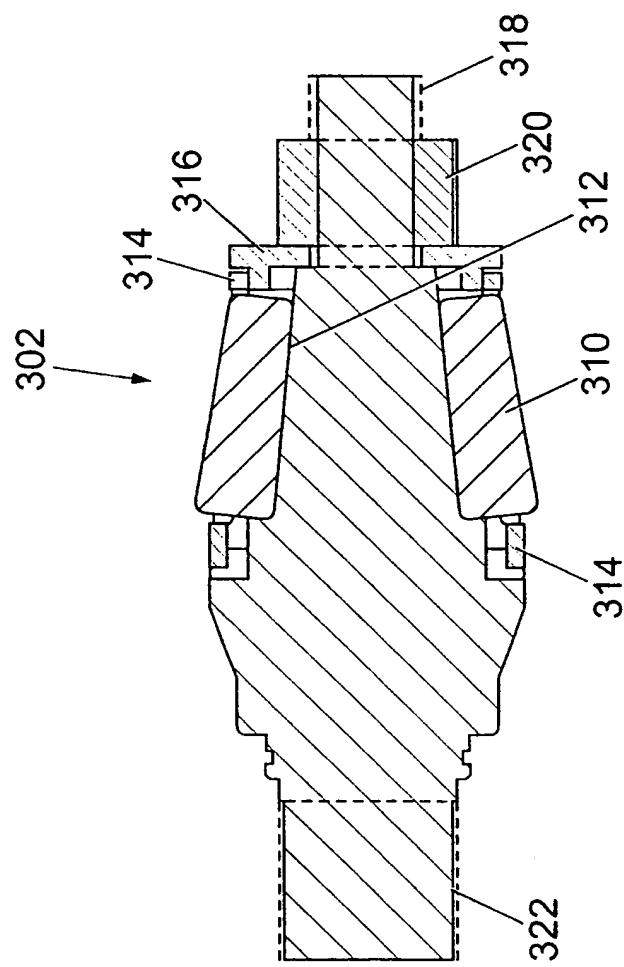


Fig. 23

19 / 25

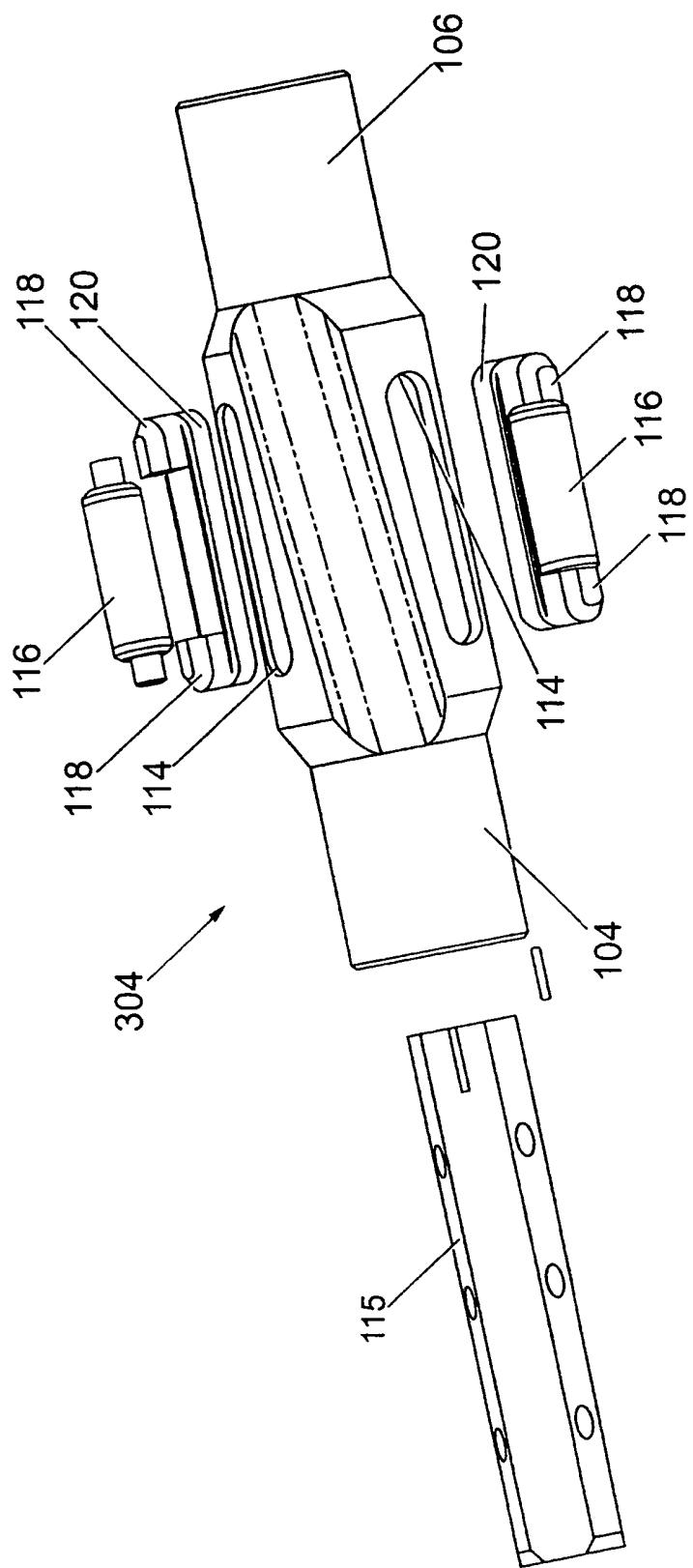


Fig. 24

20 / 25

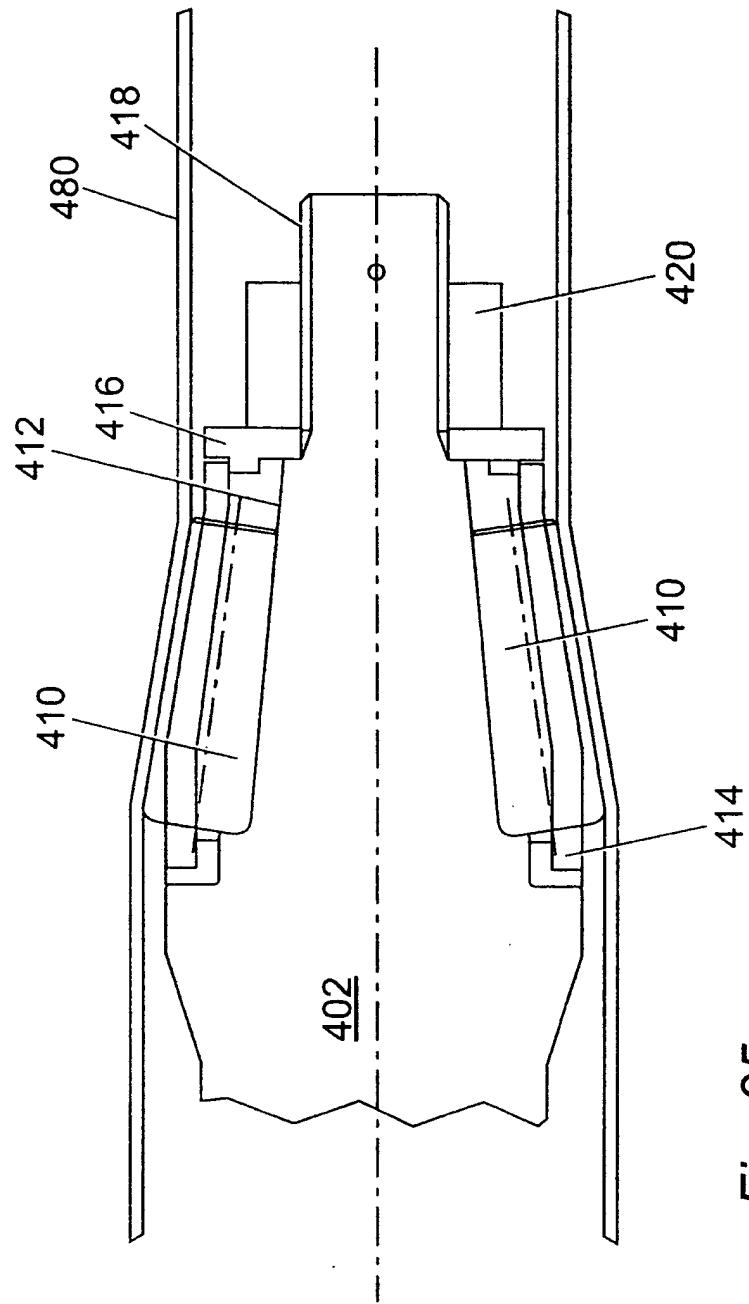


Fig. 25

21 / 25

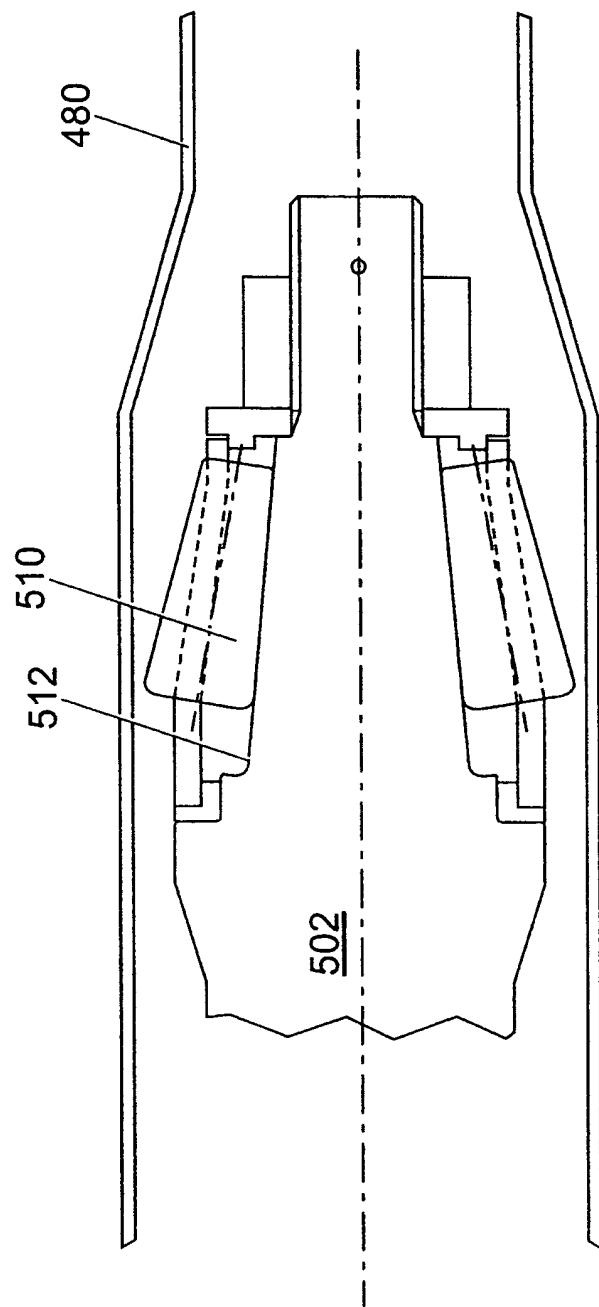


Fig. 26

22 / 25

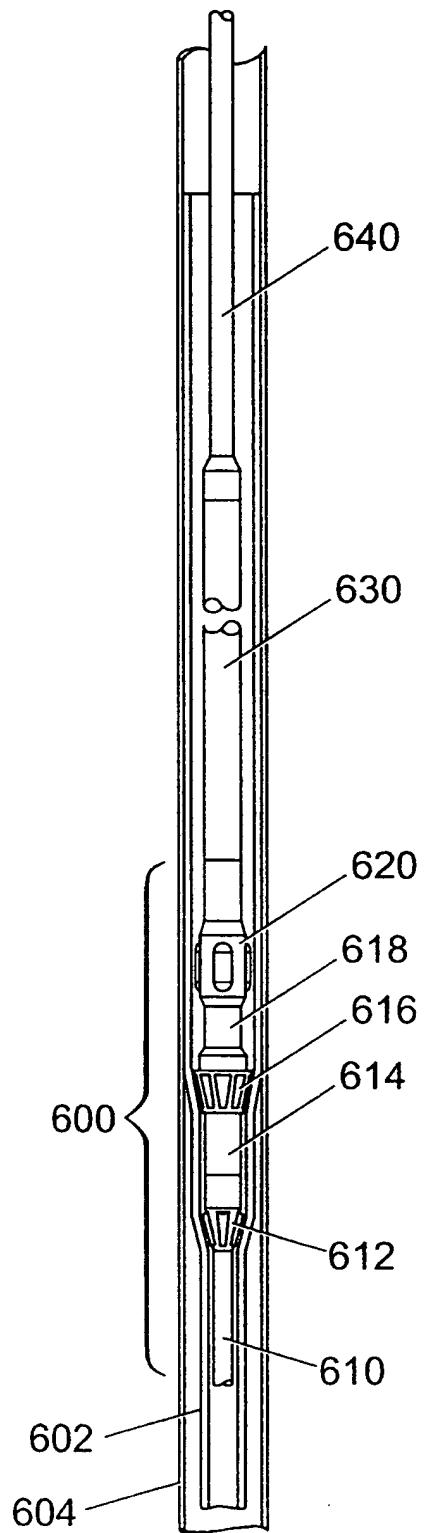
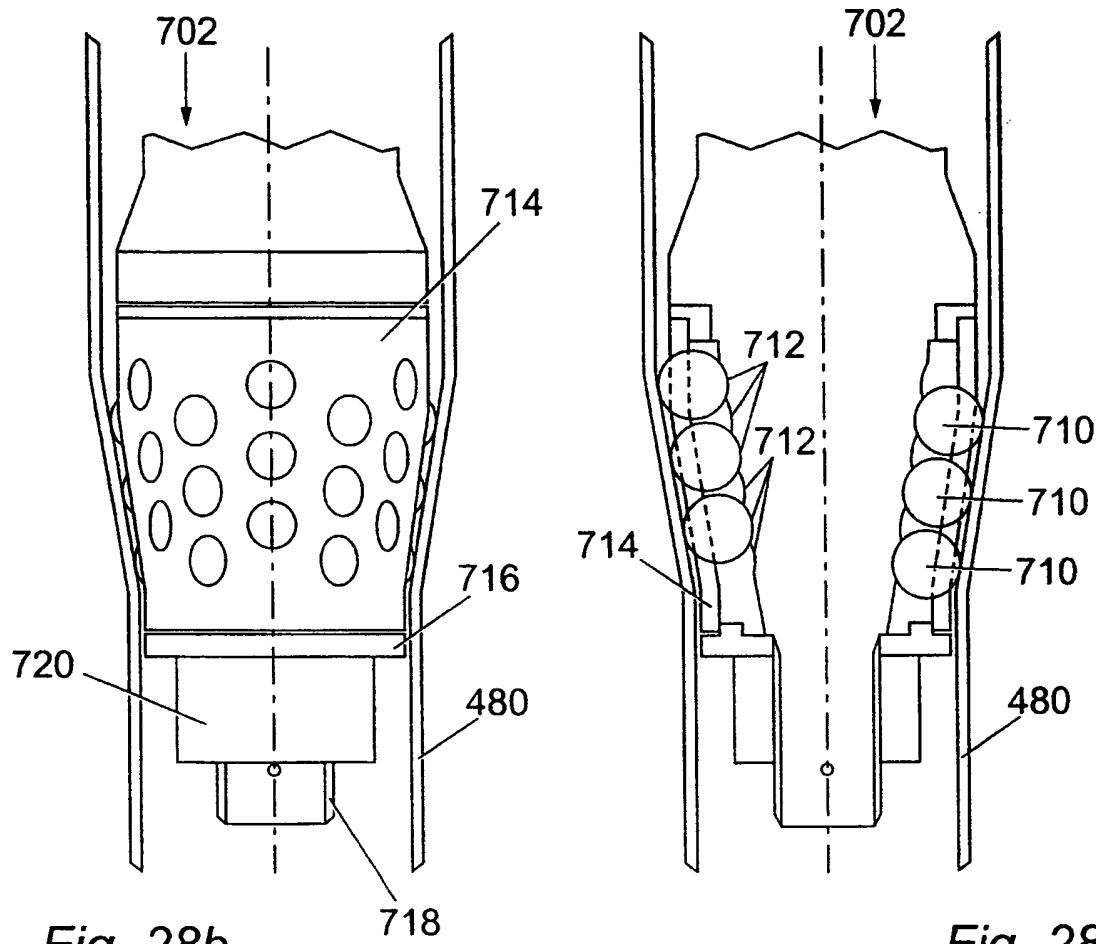


Fig. 27

23 / 25



24 / 25

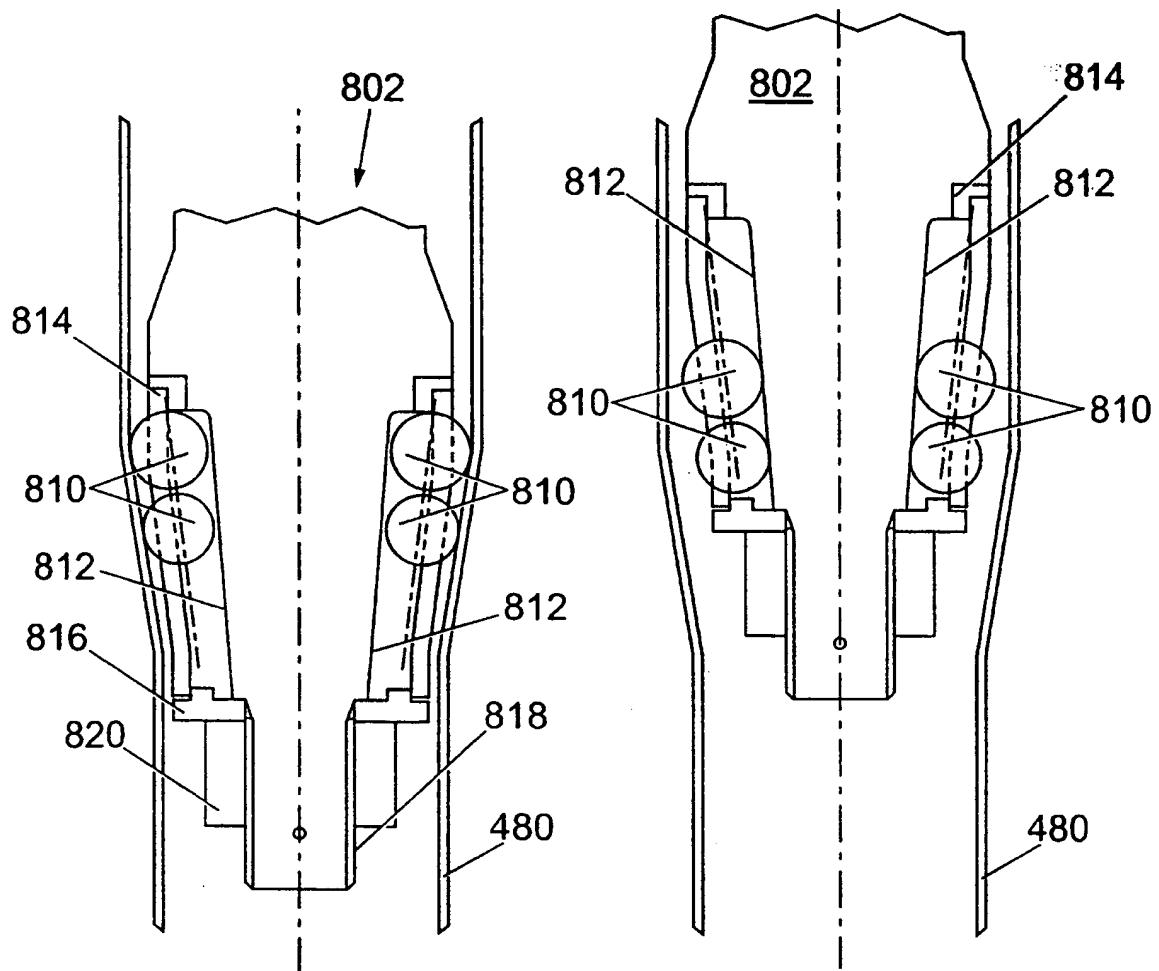


Fig. 29a

Fig. 29b

25 / 25

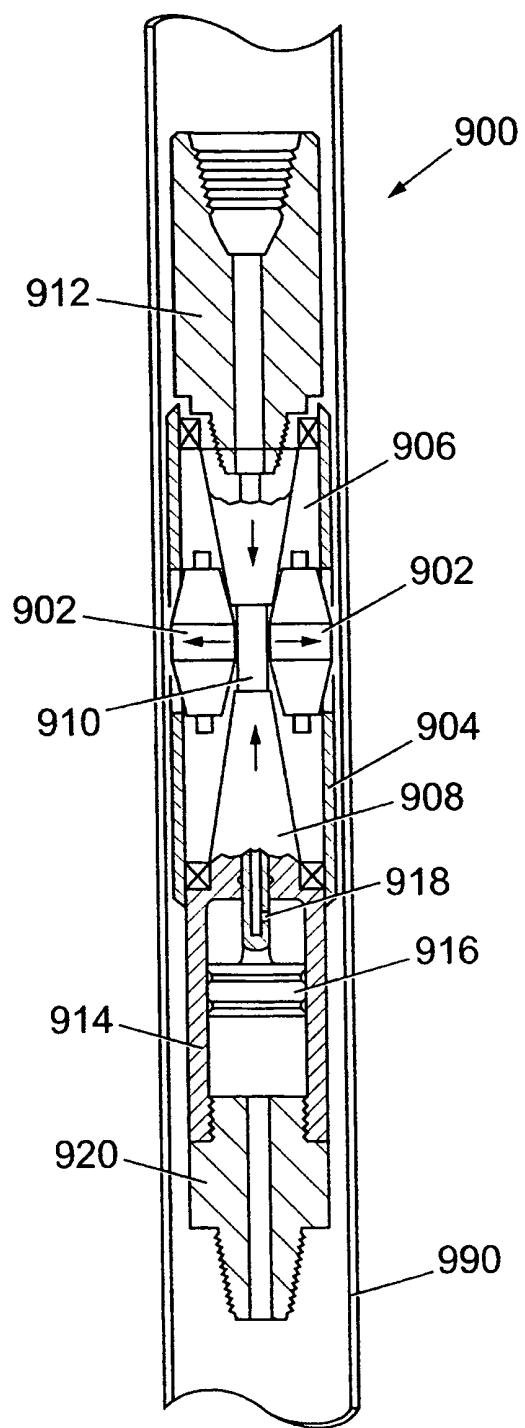


Fig. 30